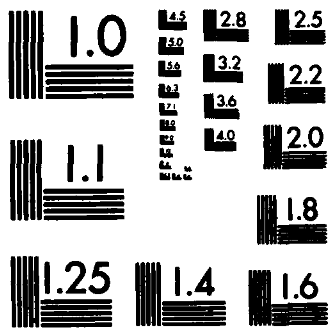
AD-A137 507 COMBINING A LEVEL OF REPAIR MODEL WITH AN AVAILABILITY CENTERED PROVISIONING MODEL FOR LOGISTIC SUPPORT ANALYSIS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA 1/2

UNCLASSIFIED H J WATRAS SEP 83 F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMBINING A LEVEL OF REPAIR MODEL WITH AN AVAILABILITY CENTERED PROVISIONING MODEL FOR LOGISTIC SUPPORT ANALYSIS

by

Henry J. Watras

September 1983

Thesis Advisor: M.B. Kline

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A137507	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Combining a Level of Repair Model with an Availability Centered Provisioning Model for Logistic Support Analysis		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Henry J. Watras		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE September 1983
		13. NUMBER OF PAGES 114
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Provisioning; Level-of-Repair; Availability Centered Inventory Model; ACIM; Systems Engineering; System Maintenance Engineering; Logistics Support Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis is a study into expected system operational availability as a function of level of repair (LOR) and systems spares provisioning. The maintenance and repair cycle for most systems is discussed with concentration on the Navy MIL-STD-1390B Naval Air Systems Command Equipment model (AIR) which determines the life support cost for various LOR policy alternatives. The thesis then

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT Continued

demonstrates how the Navy's Availability Centered Inventory Model (ACIM) may be used to determine the least cost provisioning policy to obtain a desired level of system operational availability for the specified LOR policy in a multi-echelon operation and support organization.

Approved for public release; distribution unlimited.

Combining a Level of Repair Model with an Availability Centered Provisioning Model for Logistic Support Analysis

by

Henry J. Watras
Lieutenant, United States Navy
B.A., Ohio Wesleyan University, 1976

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL

September 1983

Author: Henry J. Watras

Approved by: Melvin B. Kline, Thesis Advisor

Alan W. McMasters, Second Reader

Chairman, Department of Operations Research

K. T. Marshall, Dean of Information and Policy Sciences

ABSTRACT

This thesis is a study into expected system operational availability as a function of level of repair (LOR) and system spares provisioning. The maintenance and repair cycle for most systems is discussed with concentration on the Navy MIL-STD-1390B Naval Air Systems Command Equipment model (AIR) which determines the life support cost for various LOR policy alternatives. The thesis then demonstrates how the Navy's Availability Centered Inventory Model (ACIM) may be used to determine the least cost provisioning policy to obtain a desired level of system operational availability for the specified LOR policy in a multi-echelon operation and support organization.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

Extensive effort has been undertaken recently within the Department of Defense in the development and refinement of Level of Repair (LOR) models to aid in determining the least cost LOR policy for a particular system. The Navy has published Military Standard 1390B which details cost methods incorporated in its five equipment-specific general purpose models. The five Navy LOR models are:

(1) Naval Air Systems Command Equipment

(2) Naval Electronic Systems Command Equipment

(3) Naval Sea Systems Command Ships Equipment

(4) Naval Sea Systems Command Ordnance Equipment

(5) Marine Corps Equipment

LOR analysis is the function of specifying at what level of maintenance support a system assembly or component will be repaired or discarded. These models determine the life support costs associated with the maintenance of a system related to a specific LOR policy. These calculated life support costs are then used by the analyst to help in determination of an optimum LOR policy.

The Naval Air Systems Command Equipment Model (AIR) was chosen for primary analysis within this thesis because of the author's interest and past experience in the operation

and maintenance of Navy tactical jet aircraft deployed aboard an aircraft carrier. Also of interest is how aviation spare parts are provisioned in relation to an LOR policy and the combined effect of the spares provisioning and LOR policy on expected system operational availability.

AIR is currently the most widely used of the five Navy LOR models and is capable of handling many levels of indenture in a system component hierarchy. AIR will also handle a multi-echelon maintenance support organization.

B. OBJECTIVE

The purpose of this thesis is to propose system operational availability as a measure of effectiveness to be used during the establishment of a support policy for a system being developed.

The elements of support policy considered are the level-of-repair aspects of system maintenance and the provisioning of system components and other related repair material at the various maintenance and support echelons.

The level-of-repair and provisioning policies influence the system effectiveness achieved throughout the operational and support period of the system life cycle. System operational availability is a concept which can be used to quantify the interrelationship of level-of-repair policy and provisioning in determining expected system effectiveness.

The primary objective of this thesis is to demonstrate the feasibility of combining an LOR model with an availability

provisioning model during the formulation of system support policy.

Areas discussed in meeting the thesis objective are:

(1) The role of level-of-repair policy and spare parts provisioning in logistic support throughout the life cycle of the system;

(2) The process by which an LOR policy is formulated;

(3) The parameter inputs required for LOR analysis;

(4) The levels of provisioning necessary to obtain a specified system operational availability for different LOR policies;

(5) The system and support organization parameters required to determine appropriate provisioning.

C. APPROACH

In meeting its objective, this thesis stresses the system engineering methodology of structuring a system life cycle as a series of definable periods and phases. Chapter II is a narrative overview of the system life cycle, LOR development, and applicable measures of effectiveness as related to the system life cycle. The reciprocal impact of LOR policy on system life cycle support is then addressed in this chapter. The AIR model is discussed in Chapter V for familiarization of LOR analytical procedures.

Once an understanding of AIR and ACIM is gained, sample data describing a hypothetical avionic system operated and supported in the Navy is used to illustrate the thesis

proposal. A feasible LOR policy is determined for each item in the system. This predetermined LOR policy is chosen to illustrate a repair alternative for the purpose of sensitivity analysis of AIR versus ACIM provisioning. The sample data is processed by AIR which then determines the expected system life support cost and suggested spares provisioning levels throughout the entire support organization for the specified policy. The AIR suggested inventories at the various support locations are then used by ACIM to calculate system operational availability at each site operating the system. Finally, the system data under the specified LOR policy is evaluated by ACIM for the least cost provisioning throughout the support organization to attain a 95 percent system availability at each site or the maximum attainable system availability for a site if it is calculated by ACIM to be lower than 95 percent.

II. OVERVIEW OF ANALYSIS AND APPLICABLE MEASURES OF EFFECTIVENESS

In this chapter, measures of effectiveness concepts are discussed for assessing system availability as a function of LOR policy and provisioning. A systems engineering approach is used to define the problem, structure the analysis, determine the feasible solution alternatives, evaluate the alternatives, and finally to arrive at an optimal solution.

A. SYSTEM LIFE CYCLE

When considering a system analytically, the system life cycle is often useful in structuring system development. All systems have a definable life cycle which can be broken down into specific periods which in turn can be defined as a sequential series of phases. Figure 2.1 illustrates the time flow of the system life cycle. This thesis assumes that the reader is familiar with the life cycle concept, and the information displayed in Figure 2.1 is used throughout the thesis as a basis for many system assumptions and analytical direction. Reference 1 can be consulted for amplification of the concepts used in defining a system life cycle.

The application of the system life cycle concept to any analysis illustrates how a system is developed over a time progression. At different points in the life cycle, the system is defined by different sets of variables and fixed characteristics or constraints.

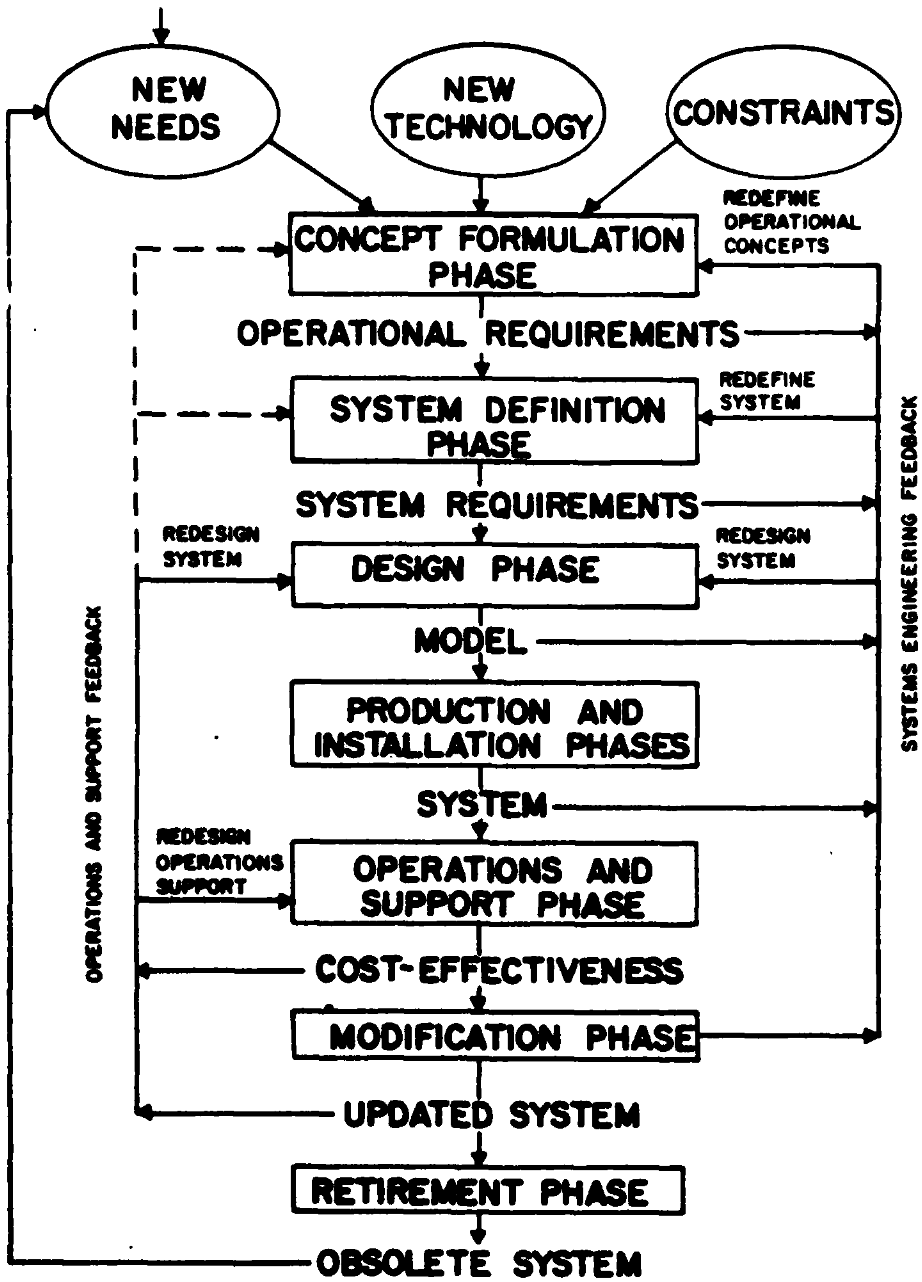


Figure 2.1. System Life Cycle [Ref. 1]

The analyses performed in the conceptual and definition phases provide a set of alternative system configurations to be considered in fulfilling a perceived mission objective. As the system is defined and developed in the design phase, many variables start to become fixed or constrained. Finally, once the system has been fully designed and tested, the system is fully constrained through design and production specifications, and there is less leeway for variation in operational employment or support.

In summary, the analyst must continually evaluate data at each point during the system life cycle which he feels best represents the system and utilize these estimates to shape support policy which will best contribute to the system's overall effectiveness.

B. SYSTEM AND SUPPORT ORGANIZATION DESCRIPTION

1. Multi-Indentured System

A multi-indentured system is designed with different levels of system (equipment) hierarchy. The arrangement of a typical system hierarchy is illustrated in Figure 2.2. The system is composed of the aggregation of all the first level indenture items. At this first level, the items are called weapon replaceable assemblies (WRA). The WRA's are assembled to form the whole system. It is conceivable that the system could include multiple uses of the same WRA.

At the second indenture level are the shop replaceable assemblies (SRA). Each WRA is made up of individual

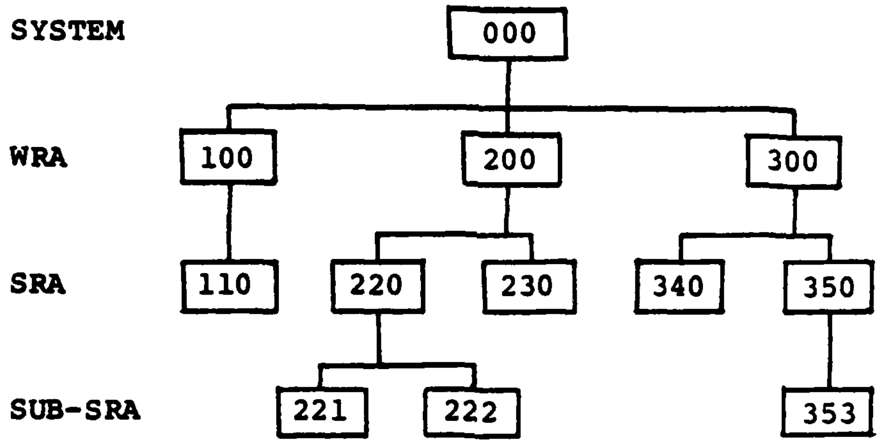


Figure 2.2. Multi-Indenture System Illustration

SRA's is the same way as the WRA's make up the whole system. Each WRA may also be composed of more than one of each SRA and a particular SRA might be found in more than one WRA.

A third and often final indenture level is represented by items or assemblies called Sub-SRA's. The assumptions of the arrangement and operation of the Sub-SRA's within each SRA are the same as for the higher indenture levels in Figure 2.2.[1]

Because of the way the AIR model treats items within the system, this thesis assumes that all items fail independently of each other. The only dependence of item failure

---

[1]The above terminology describing the different indenture-level items is exclusive to the Naval Air Systems Command. Other commands and other services use line replaceable unit (LRU) instead of WRA and shop replaceable unit (SRU) instead of SRA.

occurs when an item contained in a lower indenture-level fails. The higher-indentured assembly, of which the failed item is a part, exhibits a fault as a result of the failure.

The AIR model assumes a series reliability configuration such that the system exhibits a fault whenever any of the items within the system fails. If this is not the case for any particular item, such as parallel-configured or standby backup items, the item or items have to be modeled with a series reliability relationship within the system. This modified item data would require additional analysis outside of the AIR model.

2. Multi-Echelon Support Organization

The AIR model is capable of considering the multi-echelon maintenance support organization commonly utilized by the Navy. A multi-echelon support organization is also used in the Navy to stock inventory of spare replacement items. The stockage facilities may or may not be the same facilities which accomplish the maintenance support. Figure 2.3 illustrates a typical Navy multi-echelon support organization as used in this thesis.

The lowest level within the Navy maintenance and supply organization is called the organizational level. This level is composed of the users of the system. The organizational level may be either a land-based or ship-based site. Each organizational level usually has some limited maintenance capability associated with it. Organizational maintenance

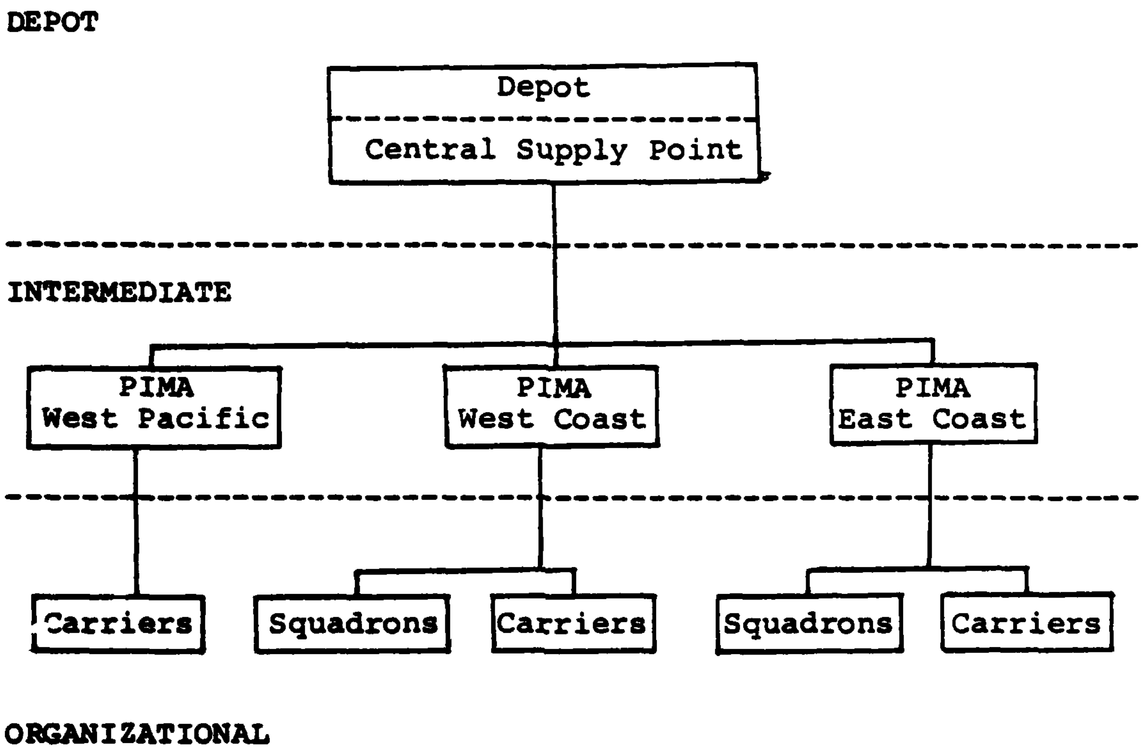


Figure 2.3. Multi-Echelon Support Organization

usually has the capability to at least fault isolate and replace a defective WRA in order to immediately restore a system to an operationally ready state. Organizational maintenance personnel may or may not have the capability to fault isolate and repair beyond the WRA level. The organizational site usually has some inventory capability in which to stock item spares used in immediate replacement of faulty items.

Some organizational sites are located at the same site as the next higher echelon os upport. This higher

echelon of support is called the intermediate maintenance activity (IMA). An IMA also has an increased inventory stockage capability. Examples of co-located organizational and IMA sites are aircraft carriers and most land based sites.

A destroyer is an example of a user which does not have an organic intermediate maintenance capability. A destroyer either requires the services of a tender or a land-based site to have intermediate maintenance performed. Some land-based organizational sites which operate only a small number of systems may also lack intermediate maintenance capability.

Since the AIR model was designed specifically to consider level-of-repair analyses for avionics applicable to most Naval aviation situations, all organizational sites are considered in this thesis to have a local IMA. Therefore, whenever the AIR model assigns an IMA LOR coding to the item, the model is specifying local repair.

Many land-based sites have an additional maintenance capability. This is possible because of the less constrained support space, availability of specially trained personnel, or extensive inventory of common or peculiar general support equipment (GSE) and other maintenance support facilities. This extra capability may not be feasible on a carrier because of extra space requirements or because it might not be cost-effective to maintain the added capability at all sites. A land-based site with the extra capability is designated a

Prime Intermediate Maintenance Activity or PIMA. Analysis often reveals that a certain item is more cost-effectively repaired at a PIMA. Both carrier and land-based organizational sites are then required to send those particular faulty items to the PIMA. This arrangement is sometimes referred to as the split intermediate alternative.

The potentially most capable of all sites is the depot. It serves lower echelon sites by providing supply support and accepting repair items beyond the maintenance capability of the lower echelon facilities. The depot usually has sophisticated test and repair equipment and highly technically qualified personnel.

In the Navy, the depot is not the highest echelon site originating supply support or spares provisioning; this function is usually handled at one of the two inventory control points (ICP). The Aviation Supply Office (ASO) in Philadelphia, PA manages avaiation related spare parts and the Ships Parts Control Center in Mechanicsburg, PA manages the spare parts for ships. There is no inventory located at either site. It is usually placed at designated stock points which are usually not co-located with a depot. However, for analytical purposes in this thesis, the depot and a central stock point are treated as one for both maintenance and inventory. The ICP usually is the only site with the authority to procure spare items from a manufacturer or supplier outside the government. The provisioning of spares

and other essential items begins at the ICP and stock point and flows through the support network to the PIMA/IMA and then to the organizational sites.

C. LOGISTIC SUPPORT ANALYSIS

Logistic support analysis (LSA) is a systems approach to planning, developing, specifying, and providing an integrated logistic support capability. LSA is an iterative management process which is used throughout the life cycle of a system to develop an integrated logistic support policy which considers the prime mission system together with its associated logistic support as a complete operational system [Ref. 2]. The Military Standard 1388 [Ref. 3] is the Department of Defense document which addresses in detail the responsibilities and procedures involved in LSA.

The 'prime mission system' refers to the equipment designed and produced to accomplish a specified set of mission functions. The logistic support system is the set of resources and functions required to maintain the prime mission system operationally ready and capable of accomplishing the specified missions.

The Integrated Logistic Support planning process may be divided into the following two areas:

(1) Maintenance engineering analysis

(2) Supply support analysis

as shown in Figure 2.4 from Reference 1.

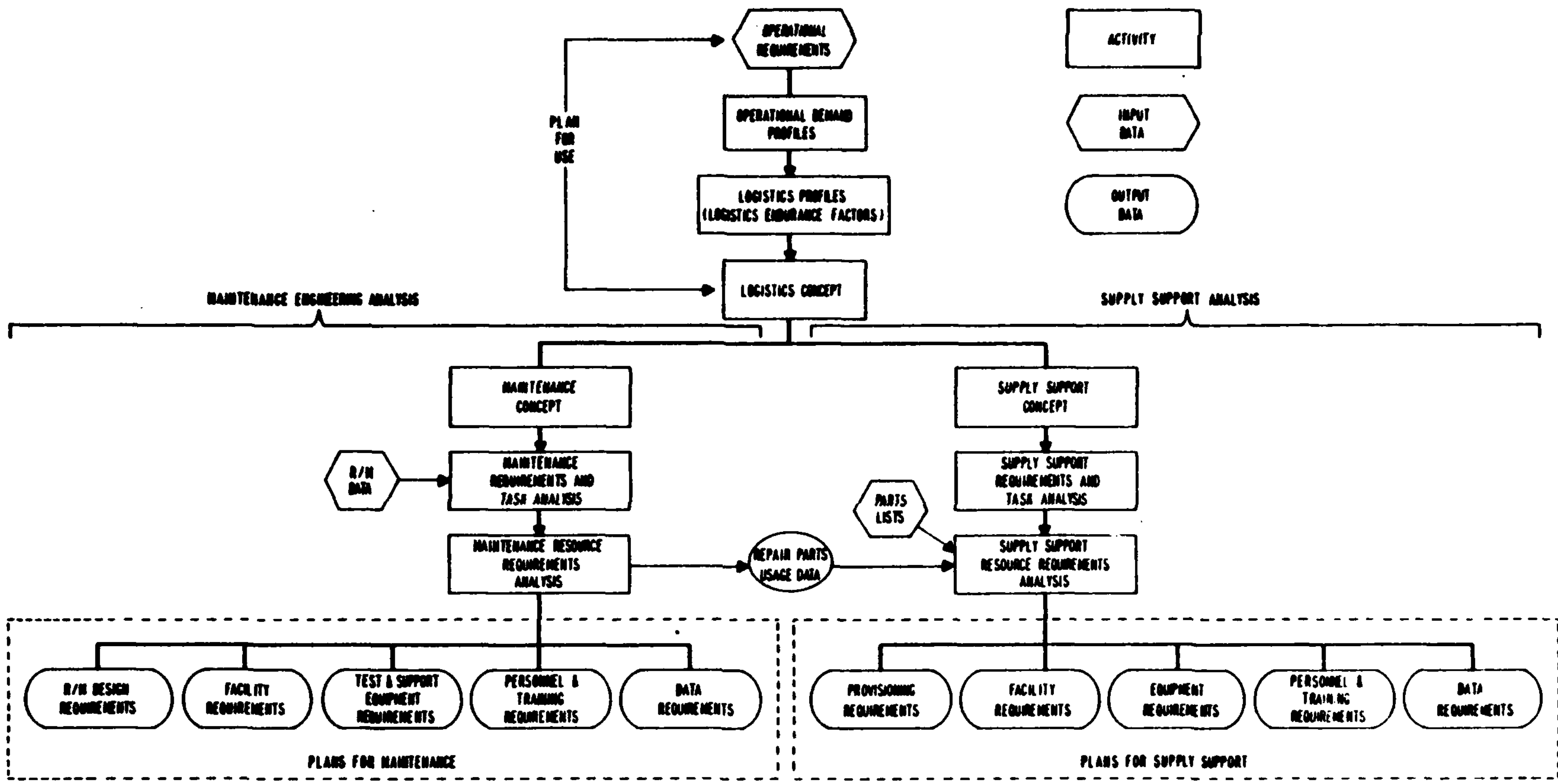


Figure 2.4. Breakdown of Logistic Support Planning Process [Ref. 1]

This thesis addresses the maintenance engineering aspect of logistic support analysis through level-of-repair analysis. Issues of supply support are then considered through the provisioning of spares to attain the optimal system availability under a specified LOR policy.

D. LEVEL-OF-REPAIR ANALYSIS

MIL-STD-1390B [Ref. 4] stresses that the LOR analysis needs to be initiated early during a system's life cycle because of the heavy influence of level-of-repair policy on system life support costs and on the system's required operational support. As stated in MIL-STD-1390B, the purpose of LOR analysis is to establish the least-cost feasible repair or discard decision alternative when performing system maintenance actions and to influence system design in that direction. LOR analysis does not include operational availability or other measures of system effectiveness as policy considerations.

One outcome of an LOR analysis is a maintenance policy regarding whether the item should be discarded or repaired at the depot, intermediate, or organizational level. The policy also becomes the basis for the maintenance and recoverability portion of the Source, Maintenance, and Recoverability code (SM&R).

The SM&R code is a five-character code reflecting the LOR coding of an item. The first two characters designate

the source of the item for procurement purposes. The source code is not applicable to the analysis within this thesis. The third character specifies the lowest echelon maintenance level which is authorized to remove and replace the item. The fourth character specifies the lowest echelon maintenance level which is authorized to repair the item. If the item is to be discarded, the fifth character designates the echelon level which may dispose of the item.

An example of an SM&R code is 'PAOFD' with 'OFD' being the LOR applicable portions of the code. The third character 'O', specifies the item may be removed and replaced in the system at the organizational level or higher. The fourth character 'F', authorizes carrier based intermediate or higher echelon repair. The fifth character 'D', specifies the depot as the only authorized to discard the normally repairable item if the item is scrapped during the repair process.

E. SYSTEM EFFECTIVENESS

System effectiveness is the quantification of a system's performance in terms of how well the system accomplishes a specific mission in the operational environment. System effectiveness is dependent on how well the system concept was formulated and how well the system was designed and produced according to those specifications.

The basic concepts defining system effectiveness are stated in Reference 1 as follows:

(1) How well will it perform in the mission environment? (Capability)

(2) Will it be ready to perform when called upon? Is it up at the start of the mission? (Availability)

(3) Will it continue to perform for the duration of the mission? (Dependability)

The following definitions are taken directly from MIL-STD-721B [Ref. 6]:

> Capability is a measure of the ability of the item to achieve mission objectives given the conditions during the mission.
>
> Availability is a measure of the degree to which an item is in the operable and commitable state at the start of a mission, when the mission is called for at an unknown (random) point in time.
>
> Dependability is a measure of the item operating condition at one or more points during the mission, including the effects of reliability, maintainability, and survivability, given the item condition at the start of the mission.

F. OPERATIONAL AVAILABILITY

Navy Material Command Instruction 3000.2 [Ref. 5] establishes operational availability (A_o) as a primary measure of effectiveness for Navy weapons and equipment. It also stresses that A_o goals and thresholds must be considered throughout the system life cycle. These goals and thresholds are to be defined in the system conceptual and definition phases and used as guidelines throughout the system design and development phase. Once a system becomes operational, A_o, based on actual field data, should be used as a basis

for ongoing logistic management review and improvement actions.

The most basic description of availability is the ratio of system up time over the total time for which there is a demand for the system.

It should be noted that availability does not refer to being able to perform satisfactorily throughout the mission. This issue is addressed by the measures of dependability and reliability [Ref. 1].

The usual expression for A_o as stated in Reference 2 is:

$$A_o = \frac{MTBM}{MTBM + MDT}; \tag{2.1}$$

where:

MTBM = mean time between maintenance;

MDT = mean downtime.

Mean downtime includes the active maintenance time and any expected additional time attributable to logistics supply and administrative delay.

The following is the official Navy definition [Ref. 5] for A_o to be used for analysis during system development.

$$A_o = \frac{MTBF}{MTBF + MTTR + MSRT} \tag{2.2}$$

where:

MTBF = mean time between failure;

MTTR = mean time to repair;

MSRT = mean supply response time.

This equation ignores preventive maintenance and administrative downtime. It also assumes an infinite number of spares or repair parts are available in the supply system which includes the manufacturer and supplier. Equation (2.2) is used throughout the remainder of the thesis when operational availability is specified because:

(1) It is the official Navy expression for A_o;

(2) It is used in ACIM calculations;

(3) It is convenient, applicable, and easy to use.

G. INHERENT AVAILABILITY

Another often used measure of system effectiveness is inherent availability. Inherent availability is a function of system design only and neglects the effect of supply support in describing system availability.

$$A_i = \frac{MTBF}{MTBF + MTTR} \qquad (2.3)$$

Inherent availability is useful when evaluating one proposed system against another strictly on the basis of system design performance.

Inherent availability can be used as the upper bound when determining operational availability. Operational availability approaches the value of inherent availability as the supply support posture improves and MSRT approaches zero. This is addressed in Section VI.B.1 when describing the concepts underlying ACIM.

H. RELIABILITY AND MAINTAINABILITY

Reliability and maintainability are important considerations in the development and design of a system. Reliability and maintainability are different yet mutually dependent engineering disciplines [Ref. 1]. Reliability and maintainability are not directly addressed in this thesis, but they are extremely important in availability analysis, LOR policy decisions, and spares provisioning.

> Reliability is the probability that an item will perform its intended function for a specified interval under stated conditions. [Ref. 6]

The exponential distribution is often used to describe times to failure. Under the exponential assumption, reliability is expressed as a function of time.

$$R = e^{-\left[\frac{t}{MTBF}\right]} \tag{2.4}$$

Equation (2.4) is also known as the mission reliability when t equals the expected time of the mission, T.

> Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a

specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources. [Ref. 6]

MTTR is one descriptor of maintainability as it estimates the mean time to restore a system to an operational status.

I. COST-EFFECTIVENESS

Cost-effectiveness analysis is the economic evaluation of several feasible alternatives pertaining to an engineered system. It aids the decision maker in choosing a preferred approach from a set of possible alternatives by relating each approach in terms of expected life cycle cost to the expected level of system effectiveness attained. By comparing the life cycle cost and ability to fulfill the specified mission of each alternative, one is able to obtain a clearer representation of the value of each alternative.

Two cost analysis methodologies which are used are the life cycle cost (LCC) method and the life support cost (LSC) method.

1. Life Cycle Cost

Life cycle cost is the method of accounting for all costs incurred throughout a system's life cycle. LCC is often used as an analytical tool during the system definition stage when several possible systems are being evaluated to meet a specific mission requirement. It is also used during the design phase for making system trade-offs.

LCC can be broken down into the main cost categories of:

(1) Research and Development Costs

(2) Production Costs

(3) Operation and Support Costs.

The first category of research and development refers to all costs accumualted during the conceptual, definition, and full-scale development phases of the system life cycle. This category typically accounts for 10-15 percent of LCC [Ref. 1].

The second category accounts for costs accumulated during the production and procurement of a new system. This category accounts for 30-40 percent of LCC [Ref. 1].

The third category of LCC costs accounts for the bulk of all costs attributable to system ownership. These costs include operations and support personnel, spares and repair parts, facilities, training, documentation, and other related costs. For a well-designed system, these costs are 40-60 percent of LCC [Ref. 1].

2. Life Support Cost

A second method of cost analysis considers only the life-support related costs of a system which is the operational and support subset of LCC. LSC covers the costs of labor, equipment, facilities, material and other direct or indirect costs required to operate and support a system during the operational and support phase of a system's life cycle.

LSC is applicable to any analysis considering support alternatives involving a system which has already been

acquired as well as one being developed. LSC is, therefore, generally more applicable than LCC as the cost-effectiveness methodology for LOR analysis. LOR analysis provides inputs for determining the LSC for each LOR policy alternative. Table I is a list of ten factors influencing LSC which are considered by AIR.

TABLE I

Factors Influencing LSC

(1) System failure rate characteristics

(2) System deployment and utilization rates

(3) Inventory and related costs

(4) Support personnel labor and training costs

(5) Repair and storage facilities

(6) Support equipment and support of support equipment

(7) Transportation

(8) Material and repair scrap

(9) Documentation

(10) Repair times

III. SYSTEM MAINTENANCE AND THE REPAIR CYCLE PROCESS

This chapter briefly describes the maintenance and repair process of a multi-echelon support organization for an avionic system consisting of a multi-indentured item hierarchy.

A. MAINTENANCE

> Maintenance is defined as all actions necessary for the purpose of retaining a system in or restoring a system to a specified condition. [Ref. 6]

Maintenance can be grouped into the following two areas:

(1) Preventive maintenance

(2) Corrective maintenance

Preventive maintenance refers to those maintenance actions which are peformed for the purpose of retaining equipment in a mission capable condition. This includes periodic test, monitoring, servicing, and inspections. Because these actions can be scheduled and are usually performed at the organizational level, they are not considered in an LOR or availability analysis. It is assumed that all preventive maintenance can be accomplished during non-operating periods or during non-critical system operating periods.

The analyses involving A_o and LOR are primarily concerned with corrective maintenance because corrective maintenance depends on failure, is unscheduled, and must be estimated as

a stochastic process. Corrective maintenance is required whenever a system is in a non-mission capable condition. Corrective maintenance can be usually divided into the four phases of: [Ref. 1]

(1) Detection: recognition of a fault;

(2) Diagonostic: fault location and isolation;

(3) Correction: replace and/or repair;

(4) Verification: test, calibration, and checkout.[2]

These four phases are used in maintainability engineering to define the repair process in terms of maintenance personnel, support equipment, facilities, and other required maintenance resources.

A fault in the system may be detected by a system operator, during a system check by a maintainer, or automatically by the system itself. A fault discovered by a maintainer is sometimes detected during preventive maintenance.

Faults occurring in a system may be classified within the following three categories: [Ref. 1]

(1) Partial degradation;

(2) Critical failure;

(3) Catastrophic failure.

The first type of fault possibly may go undetected for a long period of time. The system may be performing at such a slight reduced capability that the average operator may not

---

[2]Only diagnostic, correction, and verification times are included in the calculation of MTTR.

be aware of the difference initially. If the system is continually operated in this state, the fault may cause the system to eventually become more severely degraded or to fail catastrophically.

The second type of system fault is accompanied by a usually noticeable reduced system performance. This fault is critical in that the resulting system operation is below acceptable levels of capability or threshold. Corrective maintenance is required to restore the system to peak operating efficiency.

The third type of system fault is one in which the system is not capable of being restored to an operating condition. There is no system recovery possible and the only maintenance remedy is condemnation and complete replacement of the defective component.

Upon detection of a system fault, the corrective maintenance effort enters the second phase which is actually the beginning of the repair cycle. In the diagnostic phase, the fault is located and isolated. The purpose is to pinpoint the problem to a specific item within a lower indenture level.

A system with low maintainability may have a high false removal rate. A high false removal rate is characterized by diagnosing the wrong component as the source of the fault during the isolation phase. When this happens, the repair cycle proceeds to the next maintenance phase under the wrong

fault location assumption. A high false removal rate may be remedied by implementing more reliable detection and diagnostic techniques.

Once the fault has been isolated to the actual malfunctioning component, the maintenance process enters the third or correction phase. At this point, the identified item is either repaired in place or is removed and replaced by an off-the-shelf spare. An off-the-shelf replacement is based on the assumption that a spare is readily available from inventory. If not, then the system remains down awaiting the repair of the removed component or the arrival of a replacement spare through the supply system.

Once the diagnosed faulty component has been removed and replaced or repaired, the maintenance process moves to the final phase involving verification and final calibration if required. Verification is required after a corrective maintenance procedure has been performed for assurance that the fault was in fact corrected. If the results of the verification testing indicates the fault still persists, then the repair cycle must return to the diagnostic phase.

Often the system may need recalibration before it can be verified for operational use. This step during the final phase ensures that the system will operate efficiently and according to specification. Before the verification phase of the system is complete, the system has to undergo a final checkout to ensure that the fault was corrected.

The repair effort is an ongoing process in that replaced assemblies continue through the repair process until the fault is isolated within a lower indenture level of the assembly. This replaced assembly is then repaired as applicable and then undergoes verification for certification of fault-free operation. Upon verification, the assembly is returned to inventory in a ready for issue (RFI) status to be used as a future replacement item.

The repair process continues until the lowest indenture level possible is identified as containing the fault. At this point the fault is isolated to an item which is designated by the SM&R code for discard and replacement by a new item from stock. An item may be designated with no further authorized repair because an LOR analysis determined that discard was the cost-effective corrective maintenance policy for the item.

The faulty item is often beyond the capability of maintenance (BCM) at the site. One alternative is to send the item to the next higher echelon. One of the assumptions within LOR analysis is that a faulty item may only be sent to a higher echelon repair site. This assumption is required for AIR model logic. It is not unreasonable since only a more capable repair facility would have the necessary resources to make the needed repair.

As mentioned in Section II.D, the SM&R code reflecting the LOR policy might not authorize the removal, replacement,

and eventual repair of the faulty item at the maintenance facility local to the operating site. This also necessitates sending the faulty item to an LOR specified repair facility higher in the support organization.

B. MAINTENANCE AND REPAIR SUMMARY

The above description of corrective maintenance and the repair cycle defines the framework for the LOR objective. The analysis objective is to formulate the LOR policy which enables the cost-effective method of maintaining all systems in the highest operational state possible. The analysis must consider every item within each indenture level of a system through investigation of feasible repair and spares stockage alternatives at each echelon within the maintenance and support organization. Central to this analysis is the determination of the point at which further repair effort is no longer cost-effective and the defective item should be discarded and replaced with a replacement item from stock.

The data collection requirements for LOR analysis are formidable. When a site lacks a maintenance resource such as a peculiar support equipment for an item, the analyst must investigate all related costs involving additional training, space, labor, and other related resources required to establish the equipment at the site before considering the site in a repair alternative involving the item in question.

The LOR analyst also becomes heavily involved in defining the required corrective maintenance procedures for each component of the system in terms of task definition. Task definition includes required equipment, personnel technical proficiency, space, and time necessary for task completion. A high degree of task definition is required for accuracy of input data.

IV. PROVISIONING

In this chapter provisioning as it is applied to Aviation Supply Office cognizant items is briefly described.

A. INTRODUCTION

The Aviation Supply Office (ASO) defines provisioning as a management process for determining and acquiring the appropriate range and depth of support items necessary to operate and maintain an end item of material for an initial operating period. The provisioning process is considered to begin at the time a production contract is awarded for the system and continues through the period of time required to have the support items shipped by the manufacturer or supplier to the stockage site [Ref. 7].

This thesis is concerned only with initial provisioning which is by definition the establishment of support items within the supply system. Follow-on provisioning is concerned with subsequent acquisition of supplies from the same sources to support additional systems. Reprovisioning results when required subsequent acquisitions of supplies must come from a new source.

B. OBJECTIVES

The objective of the provisioning process is the placement of required support items in the right place in the

right quantities in order to achieve an optimal level of support with economy of operations. When considering economy as a measure of effectiveness, the idea is to avoid retaining within the supply system an overly extensive range of different items or a greater depth of an item for which there is no justifiable demand. There is also the concern of obsolescence of items in inventory resulting from modifications of design. Finally, the depth of each item must be determined so that inventory is never discarded because the useful shelf life of the item is exceeded.

Provisioning, along with LOR policy, are the bases of life cycle support. Once the LOR policy assignment of SM&R codes and individual item demand rates have been determined, provisioning analysis considers where and how much should be stocked. Because provisioning policy interacts with LOR policy to affect life support costs and system operational availability, LOR analysis should include provisioning considerations.

C. RANGE AND DEPTH

The terms 'range' and 'depth' specify the basic provisioning variables. Range determination refers to the decision of what particular items should be stocked at particular sites. It considers the cost versus benefit of including particular items at the various sites supporting the system. The cost-benefit analysis weighs the decrease of expected

supply response time for the item if the item is stocked against the item's related inventory establishment, retention, and local administration costs.

Once a range determination has been made concerning items to be stocked, the depth decision has to be made. Depth refers to the actual amount or number of each item to be stocked at the site. Depth is computed to meet the average item demand at the site for a specified self-supporting period with an added safety level or buffer stock.

D. PROVISIONING COSTS

There are many additional costs incurred from maintaining items in inventory. Besides the actual cost of the physical item itself, there are space and administrative related costs as well. Administrative costs can be separated into the following three areas:

(a) Item entry

(b) Item retention

(c) Field supply and administration

Item entry is a one time cost per item which is incurred during the initial procurement process when a National Stock Number (NSN) is established for the item. Item retention is an annually recurring cost and accounts for the cost of maintaining the item in the NSN system. Field supply administration is the annual cost per site for local management of the item.

Inventory space requirements are calculated per individual item per site even though the Navy may already own the stockage space. A value has to be assigned per dollar of stockage space investment as a measure of cost involving the opportunity foregone regarding the stocking of other item candidates.

After all related inventory costs are properly accounted for, inventory investment and related costs may be one of the greatest cost areas within system life support.

E. ASO COGNIZANT PROVISIONING

1. Provisioning at Organizational Level Sites

When a ship or shore activity supports aircraft, the site is assigned an Aviation Consolidated Allowance List (AVCAL). The AVCAL is an authorization document which lists each item or component and the respective quantity the site is designated to maintain in inventory in order to achieve self-supporting capability for a prescribed period of time. Usually AVCALs are constructed from Initial Outfitting Lists (IOL) which are determined from predicted system component rates of failure. The specified self-support periods are designated by the Chief of Naval Operations (CNO). A self-supporting period is the time interval that a site should be capable of operating over with little or no external support. The presently CNO designated self-support periods for ships is 90 days and for land based sites is 30 days. As specified

in OPNAV Instruction 4441.12A [Ref. 7], the policy regarding objective performance for AVCAL sites afloat is to be able to fill 75 percent of all requisitions from onhand stock. A shore activity supporting aircraft is required to be able to fill 65 percent of all requisitions. The supply system is to provide an overall supply availability of 85 percent.

ASO recognizes two types of item inventory:

(1) Rotatable pool;

(2) Attrition quantity.

The rotatable pool is established for items which are authorized for local repair by the SM&R code. This quantity of spares is to provide for immediate replacement of a faulty component in a system while the replaced component is inducted into the repair process. The depth of the rotatable pool should provide 90 percent protection against being short at least one unit during the average local repair cycle. The specified minimum rotatable quantity is one unit when the expected demand is one or more during a 30 day period.

The attrition quantity exists for replacement of items which are beyond the capability of local maintenance, scrapped during the repair process, or for items with a SM&R code specifying discard or higher echelon repair. The current policy is to establish an onsite attrition allowance for 85 percent confidence against being short at least one item during the prescribed self-support period.

Low demand attrition items are those which have a predicted demand of less than one unit in 90 days at a site. When estimating low demand attrition rates, the minimum replaceable unit (MRU) has to be considered. An MRU is the quantity of an item to be replaced in a system when a maintenance requirement exists for replacement of the item. Low demand items are included in an AVCAL in a quanity of MRU if one of the following conditions hold:

(1) Unit cost of 5000 dollars or more and a predicted demand of greater than 1 every six months;

(2) Unit cost of less than 5000 dollars and a predicted demand of greater than one every nine months.

Whenever an item is drawn from the AVCAL, an order is immediately sent to a local stock point for a replacement. Therefore, there is a need for system backup stock (or system stock quantity) to provide such replacements. This reordering policy is often referred to as a continuous review (S-1,S) policy.

2. <u>Wholesale Provisioning</u>

The philosophy of provisioning is different at higher echelons of support which do not operate systems.[3] The supply terminology referring to provisioning of backup stock by the Inventory Control Point (ICP) is called the wholesale level. The items provisioned at this level are defined as

---

[3]The depot has its equivalent of an AVCAL which is called a ready supply store.

wholesale system stock. The objective of wholesale system stocks is to provide inventories of items to fill demands from all the lower levels which occur during the procurement lead time and the time after the material support date when the first replenishment buy is made. The wholesale system stock must also meet item requirements during the initial depot level repair cycle (IDLRC). The IDLRC is defined as the entire depot level repairable pipeline which commences with the removal and replacement of an item to be shipped to a depot level maintenance facility and terminates with the return of the item to a ready for issue (RFI) status.

F. PROVISIONING FOR OPERATIONAL AVAILABILITY

As of March 1981, CNO has approved the use of the Availability Centered Inventory Model (ACIM)[4] in provisioning applications [Ref. 9]. Instead of provisioning item per item based on individual demand rates, ACIM utilizes marginal improvements in mean supply response time per dollar investment to iteratively determine range and depth requirements for inventory spares. ACIM adds additional items to inventory at the site which contributes greatest to reducing the mean supply response time until the target MSRT is reached at each operating site or the maximum inventory investment is exceeded. ACIM is discussed in greater detail in Chapter VI.

---

[4]The acronym ACIM is often interchangeably used with ACIR which is an abbreviation of Availability Centered Inventory Rule.

So far ACIM has been mostly limited to determining only organizational level stockage requirements for selected equipments which have had relatively low availabilities and appear to receive insufficient spares through normal supply channels in achieving acceptable levels of maintenance responsiveness [Ref. 9]. There has recently been some experimentation with ACIM at the wholesale level. Specific programs which have utilized ACIM are the LAMPS MK III helicopter and the Phalanx Close-In Weapon System.

V. NAVAL AIR SYSTEMS COMMAND LOR MODEL

A. INTRODUCTION

1. Description

The 'AIR' LOR model is a mathematical procedure for calculating whether and where avionics components should be repaired in order to minimize the system life support costs. AIR is implemented in a Simscript computer program and is capable of handling a multi-indenture level system hierarchy being supported in a three-echelon support organization.

2. LOR Alternatives

The AIR model is designed to determine the optimal level of repair or discard policy for each item within a system. For each item of the system, there are 4 alternative policies to be considered in this following order:

(1) Local repair (IMA);[5]

(2) Prime intermediate repair (PIMA);

(3) Depot repair;

(4) Discard.

For a lower indenture item, the LOR alternative must have the same or higher number in the above list than the next higher indenture assembly. The model also assumes that each assembly receives only one LOR designation. Therefore the

[5]AIR model logic assumes that an IMA is located at all organizational sites. See Section II.B.2.

LOR assignment of the item does not depend on which lower indentured item failed.

3. AIR Optimizing Routine

The AIR model has an optimizing routine which computes the least cost life support policy for any multi-indenture system. The first step is to find the least cost or optimal assignment for each SUB-SRA for each of the possible assignments for the respective SRA. Therefore, for any assignment of a SRA, its SUB-SRA assignment must be already determined. The next step is to determine the optimal LOR assignment for every SRA for each possible LOR assignment of the respective WRA. The procedure is repeated for each indenture level until the complete LOR policy for the whole system is determined. At each iteration step, the associated life support cost for the next lower indenture level is therefore determined.

4. LOR Policies

The AIR model computes the life support cost for the following 6 general LOR assignment policies:

(1) All WRA local discard;

(2) All WRA local repair, all SRA local discard;

(3) All WRA local repair, all SRA local repair, all SUB-SRA optimized[6];

(4) All WRA local repair, all SRA PIMA repair, all SUB-SRA optimized;

---

[6]The optimized LOR assignment refers to the maintenance alternative for each particular item which results in the overall least cost LOR policy.

(5) All WRA local repair, all SRA Depot repair, all SUB-SRA optimized;

(6) All items optimized.

The program will accept up to 40 user-specified alternatives along with the six standard AIR policies. The user may specify one, some, or all items by predesignated LOR coding with the uncoded items optimized by the model.

When the user specifies LOR coding for all items, no optimization is required and the model calculates the life support cost.

B. AIR COMPUTATION OF LIFE SUPPORT COST

1. Cost Categories

The AIR model calculates costs for the following categories:

(1) Support equipment

(2) Support of support equipment

(3) Inventory

(5) Inventory administration

(5) Support equipment space

(6) Inventory storage

(7) Repair space

(8) Labor

(9) Material

(10) Transportation

(11) Repair Scrap

(12) Training

(13) Documentation

The AIR model then sums these costs in computing the stated LOR life support cost. In the output reports, the cost categories are broken out and then given as percentages of total LSC for the component indenture level. The model also has the capability of performing sensitivity analyses on all cost categories as a function of specific system parameter behavior. More explicit detail of the applicable output reports involving sensitivity analyses are given in the AIR MOD III User's Reference Manual [Ref. 10].

The formulas for the cost categories are given in MIL-STD-1390B [Ref. 4]. These cost equations allow all costs to be precisely calculated when the proper input information is provided to the model.

As illustrated in Chapter VI of this thesis with sample data, AIR does not adequately provision inventory. Therefore, inventory-related costs discussed in Section IV.D are not accurately calculated by AIR. An availability optimized inventory has to be determined with its associated true inventory cost to more accurately estimate the LOR policy life support cost.

2. Cost of Repair Requirements

The AIR computation of life cycle repair costs has been criticized for grossly under-estimating the true costs through improper treatment of labor costs [Ref. 11]. However,

the model does correctly calculate labor cost and therefore life cycle repair costs if sufficiently detailed inputs are provided to the model. The detail required for accurate cost of repair calculation is discussed here.

The Naval Air Systems Command has published a guide which contains common data inputs required for performing LOR analysis on most avionic equipment [Ref. 12]. All cost data are in 1981 dollars. This guide provides inputs which are common to most LOR analyses.

The guide provides current hourly labor rates for both military and civilian personnel at various repair facilities. For military personnel, these costs include base pay, housing allowance, and other benefits due to the average avionic technician. Civilian labor wages are provided for the different aviation depots throughout the country. Along with the civilian labor rate is an hourly overhead rate which is a composite of related production and administration costs. The overhead rate summed with the wage rate is used for civilian manned and other repair sites ashore.

AIR considers only corrective maintenance actions in evaluating one LOR alternative cost against another. Even though preventive maintenance tasks are very definite cost considerations in LSC, they are not used in LOR analysis.

For accuracy in determining applicable life cycle repair costs, a system maintenance engineer has the responsibility for analyzing corrective maintenance requirements in

great detail. Each requirement has to be considered in terms of maintainability as outlined in Chapter III concerning maintenance and repair. Each requirement has to be further defined in terms of tasks for each possible alternative repair facility. Each task has to be further analyzed in terms of required common or peculiar general support equipment (GSE) and other resources needed at each site. If a site presently does not have the necessary GSE, the costs of out-fitting the site and training the required personnel must be evaluated before a site may be considered as an alternative repair site.

The AIR model considers two types of tasks used in fulfilling corrective maintenance requirements. They are:

(1) Verify tasks;

(2) Repair tasks.

Verify tasks are those required to check the existence of a component fault. Repair tasks must include fault isolation and location to the failed next lower indenture item, removal and replacement of the faulty lower item, and any final system check. The AIR model therefore aggregates the complete maintenance process into only two tasks.

For accuracy, each task must include manhours required to obtain, set-up, run, and stow GSE required for execution of the task. AIR allocates GSE storage and repair space utilized for accomplishment of maintenance tasks. AIR also considers GSE support.

The manpower type and quantity has to be specified for assignment to each task. Manpower is defined by the required training a person has to complete to be qualified. AIR uses individual manpower type attrition rates to calculate life cycle personnel training costs incurred to maintain the necessary technical expertise onboard. Repair labor, which is the labor involved in repairing a failed assembly so that it may be returned to a Ready for Issue (RFI) status, is dependent on LOR policy because the cost of repair effort varies from site to site.

The AIR model has the capability of including documentation costs for each repair task. The cost and number of each document type has to be provided. The respective task manhours should account for the effort expended in administering the required documentation.

Finally, through the optimizing procedure of the model, AIR calculates 'swap-out labor' which must occur regardless of the LOR policy of a component. Swap-out labor is the labor involved in fault locating and isolating to a failed sub-assembly.

C. AIR SPARES INVENTORY COMPUTATIONS

1. Component Replacement

AIR calculates the number of individual components which annually require replacement at each site. This calculation is then used as the basis for calculating the number

of items repaired, items scrapped, items discarded, and the item inventory level for the site.

The annual number of real failures for a specific component at a specific site is calculated as follows:

$$\mathrm{RFAIL} = \frac{\mathrm{NITEM} \times \mathrm{OPRATE} \times 12}{\mathrm{MTBF} \times \mathrm{DEG}} \times \sum_{i} [\mathrm{MHOUR}(i) \times \mathrm{NAC}(i) \times \mathrm{D}(i)] , \qquad (5.1)$$

where:

NITEM = replications of component per system;

OPRATE = ratio of component operating hours to system hours;

MHOUR(i) = average monthly operating hours per month for aircraft type i;

NAC(i) = number of aircraft type i at the site;

D(i) = deployment factor as a fraction of a year for aircraft type i at the site;

MTBF = component mean time to failure;

DEG = degradation factor which, when multiplied by the predicted MTBF yields a reasonable estimate of the operational MTBF; and

i = aircraft type.

Using RFAIL, AIR next calculates the annual number of the component for disposition at the site by applying the false removal rate and false removal detection rate.

$$\mathrm{DISP} = \mathrm{RFAIL}[1 + \mathrm{FRR}(1 - \mathrm{FDR})] , \qquad (5.2)$$

where:

$$FRR = \text{false removal rate for the item; and}$$

$$1\text{-}FDR = \text{rate of false removals undetected.}$$

DISP is therefore the annual number of that particular component which will require a spare replacement in stock in order to immediately restore the next higher indenture level component back to operational status.

2. Rotatable Pool Quantity

When the LOR coding allows for local repair of the component, the site is allowed a rotatable pool quantity as per ASO provisioning policy to replace items failing during the local repair cycle. The number of annual local repairs to a component at a site is calculated by AIR as:

$$NREP = RFAIL \times (1-BCM) \times (1-SCR) \quad , \tag{5.3}$$

where:

BCM = rate which repairable item is beyond the capability of local maintenance; and

SCR = item scrap rate.

This equation reveals that AIR does not attempt to locally repair items which were falsely removed but not detected as such. AIR must, therefore, consider the verify task to be completely effective in identifying falsely removed items which were also undetected during removal.

From the annual number of component repairs for an item, AIR determines the average number of component failures during the average repair cycle at the site. This quantity is called the raw rotatable quantity by AIR and is calculated as follows:

$$\text{RAWRP} = \frac{\text{NREP} \times \text{RTIME}}{365 \times \text{DSITE}}, \tag{5.4}$$

where:

RTIME = average repair cycle time for the site in days;

DSITE = site deployment factor which is a weighted average of the deployment factors for the different aircraft types at the site.

This formula reintroduces the deployment factor in order to consider the expected number of failures occurring during a repair cycle when the site is fully deployed and operating the systems for average amount of time for the site.

Once RAWRP is determined, AIR determines the final rotatable pool for the item at the site as shown in Table II.

In his critique of the AIR model [Ref. 13], Neches reports that the rotatable pool (RP) quantity attempts to provide a 95 percent protection against stockout of the item at the site and that this is based on the assumption of a Poisson distributed number of failures for the item during the repair cycle. He further states that Table II is derived

TABLE II

Integeration Rules for Calculating
Rotatable Pool [Ref. 4]

RAWRP	RP per site
< 0.1	0
0.11--0.59	1
0.60--1.29	2
1.30--2.09	3
2.10--2.89	4
2.90--3.89	5
> 3.89	Closest integer (RAWRP+1)

from the approximate similarity of the Poisson distribution in the right-hand tail to the Normal distribution. Because the mean equals the variance for Poisson distributed random variables, a 95% confidence level of providing for all item failures occurring during the repair cycle can be estimated by:

$$RP = INT[RAWRP + 1.645 \times \sqrt{RAWRP}] , \qquad (5.5)$$

where INT represents the operation rounding to the next highest integer.

Neches also offers a comparison for quantities calculated by AIR using Table II criteria against Poisson calculated and Normal approximations for rotatable pool quantities

(Table III). For the Poisson and normal approximation of RP, the numbers within the parentheses adjacent to each quantity in the table represents the percent confidence level, for the respective method of calculation, against stockout with that particular RP quantity. The confidence level adjacent to the AIR calculated quantities using Table II criteria represents the Poisson calculated confidence level for that particular RP quantity.

Table III points out that when the predicted demand is less than 1.0 during the local repair cycle, AIR provisions quite adequately. Above a demand of 1.0, AIR consistently provides fewer rotatable spares than required for a 95 percent probability against local item stockout. Neches further points out that provisioning for stockout protection per individual item would lead to a total system stockage confidence level of:

$$CL = \prod_{i=1}^{N} P(i) \tag{5.6}$$

where:

$P(i)$ = confidence level against stockout for item i; and

N = number of individual components in the system.

3. Attrition Quantity

AIR provides user sites with an attrition quantity to provide spares for items not authorized for local repair,

TABLE III

Demand Related Inventory Approximations [Ref. 13]

DEMAND	On-Site Quantities AIR	POISSON	NORMAL APPROX.
0.2	1 (98)	1 (98)	1 (98)
0.3	1 (96)	1 (96)	2 (96)
0.4	1 (94)	2 (99)	2 (99)
0.5	1 (91)	2 (99)	2 (98)
0.6	2 (98)	2 (98)	2 (97)
0.7	2 (97)	2 (97)	3 (95)
0.8	2 (95)	2 (95)	3 (99)
0.9	2 (94)	3 (99)	3 (98)
1.0	2 (92)	3 (98)	3 (98)
2.0	3 (86)	5 (98)	5 (98)
3.0	5 (92)	6 (97)	6 (97)
4.0	5 (79)	8 (98)	8 (98)
5.0	6 (76)	9 (97)	9 (97)
6.0	7 (74)	10 (96)	11 (98)
7.0	8 (73)	12 (97)	12 (97)
8.0	9 (72)	13 (97)	13 (97)
9.0	10 (71)	14 (96)	14 (96)
10.0	11 (70)	15 (95)	16 (97)
11.0	12 (69)	17 (97)	17 (97)
15.0	16 (66)	22 (97)	22 (97)
20.0	21 (64)	28 (97)	28 (97)
50.0	51 (59)	62 (95)	62 (95)
100.0	101 (54)	117 (95)	117 (95)

scrapped items, or for items BCM for local maintenance. The requires days of attrition quantity stock is discussed in Section IV.E concerning the designated self-supporting period.

If an item's LOR code does not authorize local repair or the item is designated for discard upon failure, then a raw attrition quantity is computed as:

$$\mathrm{RAW} = \frac{\mathrm{DISP} \times \mathrm{RDAY}}{365 \times \mathrm{DSITE}}, \tag{5.7}$$

where:

RDAY = the designated self-supporting period.

If the local site is authorized to repair the item, then attrition quantity is calculated to provide for items scrapped during repair and items BCM for the site. The raw attrition quantity is calculated from:

$$\mathrm{RAQ} = \frac{[\mathrm{DISP} \times \mathrm{BCM} + \mathrm{NREP} \times (1\text{-}\mathrm{BCM}) \times \mathrm{SCR}] \times \mathrm{RDAY}}{365 \times \mathrm{DSITE}}. \tag{5.8}$$

The final site attrition allowance quantity (AQ) depends on the item unit price, RAQ, and rotatable quantity (RP). The following conditions specify AIR AQ determination where the INT operation specifies rounding off to the nearest integer:

(1) If RP = 0, item cost > \$5000, and RAQ < 1/2, then AQ = 0

(2) If RP = 0, item cost > \$5000, and RAQ > 1/2, then AQ = INT(RAQ)

(3) If RP = 0, item cost < \$5000, and RAQ < 1/3, then AQ = 0

(4) If RP > 0, RAQ < 1, then AQ = 0

(5) If RP = 0, item cost < \$5000, and 1/3 < RAQ < 1, then use AQ Table conversion

(6) If RP = 0, item cost < \$5000, and RAQ > 1, then INT(RAQ), use AQ Table conversion

(7) If RP > 0, RAQ > 1, then INT(RAQ), use AQ Table conversion.

The AQ Table is presented in detail in MIL-STD-1390B [Ref. 4]. MIL-STD-1390B states that this table is based on ASO range and depth criteria for computing allowance quantities. The AQ Table provides AQ as a function of unit price and RAQ. Regardless of the item cost, the least assigned attrition quantity for an item in the AQ Table is based on the normal approximation for the Poisson number of failures during the self-supporting period but resulting in an assigned quantity similar to those in column one of Table III.

The application of the AQ Table conditions in determining the sites allowance quantity results in the stocking of a greater quantity of less expensive items as compared to a more expensive item with the same demand.

4. System Stock Quantity

The AIR model does not explicitly consider a continuous review ordering policy, but does allow for a system stock quantity (SSQ) to be procured to satisfy demands due to anticipated losses during the procurement lead time (expected demand plus some safety stock--user specified). The SSQ is also used to replace quantities caught in repair cycles or supply lead times exceeding required days of stock. AIR does not designate exactly where SSQ is stocked, but it is assumed to be at the highest echelon when the items are not actually in supply transit. This assumption is based on the similarity of the AIR calculation of the system stock quantity to wholesale level provisioning. An abbreviated equation describing SSQ is as follows:

$$SSQ = PST \times IDIS + \sum_{i} [XTIME(i) \times NONRP(i)] , \qquad (5.9)$$

where:

PST = procurement leadtime + desired safety level in years;

IDIS = annual number of the items which are scrapped throughout all organizations;

XTIME(i) = repair cycle (in a fraction of a year) from echelon i to higher echelon repair facilities minus the required fraction of a year stock at echelon i;

NONRP(i) = total annual number of items sent to higher echelon repair facilities from echelon i; and

i = site operating the system.

Any XTIME(i) is not considered whenever it is less than zero.

5. Inventories at Non-User Sites

It should be pointed out that higher echelon sites are not allowed a rotatable pool or attrition quantity with the exception of the system stock quantity. This is because AIR attempts to follow ASO guidelines specifying rotatable and attritions quantities only at user sites. AIR was not developed to be a provisioning model but rather as a repair/ discard decision model and, therefore, is indifferent to system supply responsiveness. The model was developed to reflect costs associated with an LOR policy as accurately as possible and the provisioning developed within AIR attempted only to reflect cognizant policy for the purpose of estimating inventory related costs.

VI. AVAILABILITY CENTERED INVENTORY MODEL

This chapter introduces the Availability Centered Inventory Model (ACIM) and briefly describes concepts used by ACIM to determine the system A_o at an operating site.

The model utilized in this thesis is the ACIM 2.0 version as implemented by the author for use on the NPS IBM 3033. Except for JCARD[7] formatting and features mentioned below, the ACIM 2.0 User's Handbook [Ref. 15] should be consulted for further information.

A. INTRODUCTION

ACIM is a PL/1 computer model used to calculate spare parts inventory requirements for all items in a multi-indentured system at designated stockage locations throughout a multi-echelon supply support system. The model may be used for determining inventory requirements for one of the following purposes:

(1) Maximum system A_o within a target inventory investment;

(2) Least cost inventory investment to achieve a specified system A_o at various sites.

The model also has the capability of comparing an ACIM determined stockage policy to one of the following stockage policies:

---

[7]JCARD data refers to a group of input data cards used in ACIM. This group of cards is used to input additional or optional information about particular items in the system.

(1) Maintenance Criticality Oriented (MCO) Consolidated Allowance List (COSAL) policy;

(2) .25 FLSIP COSAL policy;[8]

(3) Center for Naval Analyses (CNA) Modified COSAL policy;

(4) User-specified item inventory levels at the various supply sites;

(5) User-defined protection policy against individual item stockout;

(6) Department of Defense INST 4140.42 provisioning policy;

(7) Uniform Inventory Control Point wholesale policy.

Reference 7 may be used for amplifying information on many of the standard provisioning policies listed above.

The fourth comparison capability is the applicable ACIM feature used in this thesis. The different site inventory levels calculated by the AIR model are inserted for comparison with an ACIM determined inventory.

B. MODEL THEORY

1. Availability Calculation

The model utilizes the following formula for calculating A_o as explained in Section II.E.

---

[8]FLSIP is an acronym for the Fleet Support Improvement Program. The .25 reflects the establishment of a demand cutoff of .25 per year (or 0.0625 per quarter) for stockage of an item. If the demand rate at the site per quarter is equal to or greater than 1.0, then a stockage level is established for a 90 percent protection against stockout of the item at the site. When the quarterly demand rate at the site is between 0.0625 and 1.0, then the minimum replaceable unit (MRU) of the item is stocked. Otherwise, the item is not stocked at the site.

$$A_o = \frac{MTBF}{MTBF + MTTR + MSRT} \tag{6.1}$$

ACIM requires MTBF and MTTR as inputs. System MTTR is the fault isolation, removal, and replacement of the faulty WRA. Both models assume this can be accomplished at the organizational level. These inputs are estimated parameters for the system if it is still in the development and design phase. The model takes the above formula and divides both the numerator and denominator by MTBF. The result is:

$$A_o = \frac{1}{1 + FR \times (MTTR + MSRT)} , \tag{6.2}$$

where:

$$FR = \text{failure rate of the system} = 1/MTBF.$$

For a site operating a single system, the model determines maximum A_o through the above equation by setting MSRT to zero (which is also equivalent to the system inherent availability). For a site which operates N identical systems, ACIM calculates the maximum availability[9] that the site could expect to attain as:

$$A_o^* = \frac{1}{1 + FR \times N \times MTTR} . \tag{6.3}$$

[9] A_o equation (6.3) is not actually a system A_o. A more appropriate term for the ACIM calculated A_o is site A_o. ACIM calculates A_o for the site and is a function of the operational status of all systems at the site. The exponential system failure rate at a site therefore equals N/MTBF.

Equation (6.3) indicates that maximum attainable A_o at a site is not influenced directly by LOR policy. The most influential parameter is system MSRT which may approach zero under any LOR policy. The goal for spare parts provisioning is, therefore, to develop an LOR policy which allows MSRT to approach zero least inexpensively in terms of inventory required at each site.

The model also assumes exponential rates of failure for all items in the system. Because of the exponentially distributed times to failure, the number of system failures during a time period are Poisson distributed. An item stockage policy could never actually achieve a MSRT of zero because the Poisson distribution allows some probability for an infinite number of item failures to occur within any time period.

2. Stockage Determination

Because ACIM assumes the continuous review ordering policy described in Section IV.E, the operating site orders a replacement item from the next higher facility each time an item is removed from stock or whenever the site cannot fill the item demand through on-hand stocks. Once received by the ordering site, the item is used to fill the demand or replace the item removed from stock if the site has a defined allowance for stocking the item in inventory.

The model does not allow for lateral transfer of spare parts within the same echelon of support or supply

from a lower echelon. These supply constraints are not exactly true in real practice but they are assumed in the model logic.

The model recognizes that a failed item must be shipped to the facility authorized by the SM&R code to repair the item. The model allows the item to become ready for issue (RFI) after a completion of the average repair cycle time for the repair facility. Once RFI, the repaired item is then returned to stock at the repair facility or at another site supported by the repair facility with an allowance for stocking the item.

If an item is specified to be discarded after failure, then the ICP acquires a replacement after a specified supply procurement leadtime. The item manufacturer is considered to have an infinite supply. Once acquired by the ICP, the item moves through the supply network until it reaches the ordering site. This item movement is defined by lead times required for a lower echelon to receive supplies from the next higher facility. Scrapped items are treated similarly to discarded items.

The model appears to use the concepts of rotatable pool and attrition quantities in determining inventory effectiveness in meeting item demand at a site.

The model uses an iterative process which determines for each iteration, the number of items and where they should be placed to achieve the lowest mean supply response time

(MSRT) per dollar invested for that item. Alternatively, the model determines the item and respective stockage facility which decreases MSRT most significantly for the organizational level per dollar spent.

MSRT represents the expected delay time for a site to receive a part upon demand through the multi-echelon support organization. ACIM expresses MSRT as the ratio of the expected number of backorders over the mean stock replenishment time T to the mean demand rate λ

$$MSRT = \frac{1}{\lambda} \sum_{X=S}^{\infty} (X-S) \; Pr(X;\lambda T) \qquad (6.4)$$

where:

- S = initial stock level of the item at the site; and
- $Pr(X;\lambda T)$ = Poisson probability of X units of the item being demanded during time T.

T is calculated by the model through the equation:

$$T = Pa(R + R') + (1-Pa)(L + L') \qquad (6.5)$$

where:

- Pa = probability of the item not repairable at this site;
- R = average supply lead time from the next higher supply source;
- R' = additional resupply time from if the item is not in stock at the next higher supply facility;

L = Local repair cycle assuming the repair parts are in stock;

L' = extra repair time required if repair parts are not immediately in stock.

The system MSRT at a site is a weighted sum involving the failure rate values and the MSRT at the site for items at the first indenture level. The MSRT for the first indenture level items is calculated as a function of repair cycle time, MSRT for lower indentured items, and MSRT for the item itself from higher echelon support facilities.

In Equations (6.4) and (6.5), H, Pa, R, and L are user inputs to the model. The other parameters are expected values which have to be updated after each model iteration of item placement somewhere in the support organization.

For higher echelon sites, such as the PIMA's and depot, the probability distribution of demands during time T is a compound Poisson process. The item demand rates from all the next lower echelon sites the facility supports are summed together to derive the item compound Poisson demand rate for the facility.

The depot item demand rate is the compound Poisson demand of all the intermediate sites. The depot also uses a (S-1,S) ordering policy and, therefore, orders from the manufacturer or stock point each time the depot inventory has a unit reduction of stock. The manufacturer or stock point is considered by ACIM to have an infinite inventory. The depot, as modeled by ACIM, never considers a minimum

reorder point or an economic order quantity as actual practice would dictate.

The iterative process continues until the target inventory investment level or the supply organization provisioning level is such that an additional unit of any item in inventory does not appreciably decrease MSRT. The model calls this a "saturation point"--the expected overall system MSRT is less than 0.001 day (approx. 1.5 minutes) at the site. This low MSRT results from the ACIM assumption of a zero supply response time for an on-hand item.

Figure 6.1 graphically illustrates the result of the ACIM provisioning process.

The curve represents the maximum A_o, corresponding to the minimum MSRT, which it is possible to achieve under a specified level of investment.

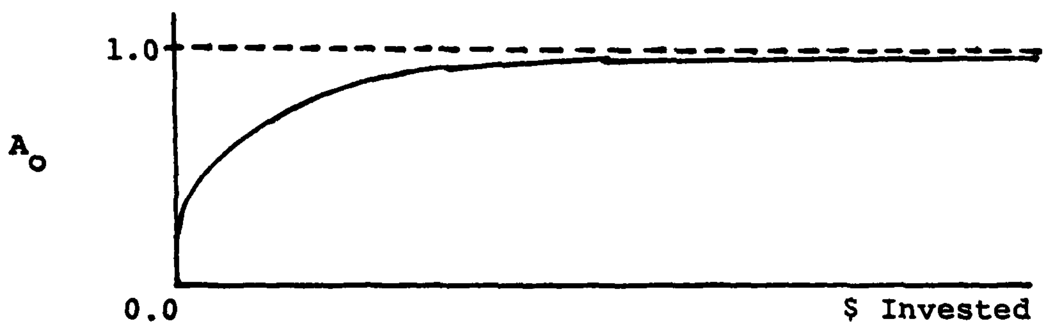


Figure 6.1. Maximum Availability Per Investment in Inventory [Ref. 9]

Notice at zero dollars of investment the curve does not intersect the A_o axis at zero. This is because the

Poisson distribution and reliability theory allow a small probability for no component failures.

Also notice that the curve is asymptotic to a value less than 1.0. This corresponds to the point of provisioning saturation to which MRST is decreased to the minimum MSRT. At the point of provisioning saturation, the system's MTBF and MTTR dominate the A_o equation.

Equivalently, the curve in Figure 6.1 also demonstrates the decreasing marginal improvement of system A_o as spares provisioning investment becomes greater. This is shown by the flattening of the curve to the right.

VII. AIR PARAMETER ADAPTATION TO ACIM INPUT REQUIREMENTS

This chapter describes how data inputs for AIR were transformed into the format required for ACIM.

A. SYSTEM MEAN-TIME-TO-REPAIR

The first card input for ACIM has a data field for MTTR. MTTR as defined for ACIM, refers to the mean-time-to-repair a system at an organizational site. ACIM requires MTTR to be expressed as a decimal fraction of a day.

To calculate system MTTR, this author used an expected value approach to estimate the expected time required to locate and isolate a previously detected system defect and then to remove, replace, test, and verify full system operation. This can be calculated as follows:

$$\text{RRTIME} = \sum_{i} [P(\text{WRA}(i)) \times \text{MTTR}(i)] \,, \qquad (7.1)$$

where:

P(WRA(i)) = the probability that WRA(i) contains the fault;

MTTR(i) = mean time to fault locate, isolate, remove, replace, and final check the system given that WRA(i) contained the fault.

This information is obtained from the respective AIR model task input data.

B. COMPONENT DEMAND RATE

ACIM does not consider MTBF for each system component directly as the AIR model does. Instead, it requires the Best Replacement Factor (BRF) for each item. The Standard Data Element Dictionary [Ref. 14] defines BRF as the total annual replacement for the item divided by the item population. One can therefore calculate the BRF for each item from the MTBF used in AIR. The transformation procedure used in this thesis is as follows. First the mean time between removals (MTBR) for the item must be calculated.

$$MTBR = MTBF \times [1 + FRR \times (1 - FDR)] \, , \tag{7.2}$$

where:

FRR = false removal rate; and

FDR = false removal detection rate.

Next, the total annual system operating hours (THOUR) must be calculated.

$$THOUR = \sum_{i} [N(i) \times MHOUR(i) \times 12 \times D(i)] \, , \tag{7.3}$$

where:

N(i) = number of systems at site (i);

MHOUR(i) = average number of operating hours per system per month at site (i); and

D(i) = deployment factor for site (i).

Next find total annual replacements for the component

$$\text{TREP} = \frac{\text{THOUR}}{\text{NITBM} \times \text{MTBR}}, \qquad (7.4)$$

where:

NITEM = number of the item in a system.

The component population is calculated by

$$\text{POP} = \sum_{i} [\text{N(i)} \times \text{NITEM}] \qquad (7.5)$$

Finally

$$\text{BRF} = \frac{\text{TREP}}{\text{POP}} \qquad (7.6)$$

ACIM uses the BRF to calculate the item Poisson failure rate at a site (i) for time T as follows:

$$\text{Item Daily Failure Rate} = \frac{\text{BRF} \times \text{NITEM} \times \text{N(i)} \times \text{OPER(i)} \times \text{T}}{365} \qquad (7.7)$$

where:

OPER(i) = the system operational usage rate at site (i) which is explained with detail in Section E.2 of this chapter.

C. SM&R CODES

ACIM uses the third and fourth digits of the SM&R code to determine where in the multi-echelon support organization the item can be repaired. The model will only consider a three-echelon support system, and, within any echelon, it does not rank repair capability for different sites within the same echelon as is done in actual practice. This means that, for both required positions of the item SM&R code in ACIM, any of the following code conventions may be used to describe a maintenance alternative for an item.

Organizational level repair --------------- 2,3,4,5,6,O

Prime intermediate level repair ----------- F,G,H,J

Depot level repair ------------------------ D,C,L

Discard ----------------------------------- X,Z

The SM&R code definitions are listed in the Standard Data Element Dictionary [Ref. 14]. For the analysis in this thesis, 'O' is used to designate organizational level repair, 'H' is used to designate PIMA repair, 'D' is used to designate depot repair, and 'X' is used to designate the discard LOR alternative.

The third position of the SM&R code states the lowest echelon which may remove the item from the next higher indenture level item. For all WRA's this position must specify organizational repair because a model assumption is that the least capable organizational level may at least fault isolate, locate, remove and replace at the WRA level

in order to restore the system back to operational status. Also for program logic, the third position code designation may not indicate a lower echelon than the repair designation of the next higher indenture level.

The fourth position of the SM&R code states the lowest echelon which may repair the item. For logical purposes, the fourth position code may not designate a repair echelon lower than the third position (which indicates the echelon which may remove the item).

D. MISSION ESSENTIALITY CODES

ACIM has the capability of considering mission essentiality codes (MEC) for the different items. MEC codes are used in some provisioning policies to indicate the criticality of the item to the system's ability to perform its specified mission. Because AIR does not have the ability to consider item essentiality, this thesis application requires modeling all items as vital to system operation. The MEC default value of 1 is therefore assigned to all items. Also when using ACIM for AIR suggested site inventory levels comparison, the run option program coding should indicate MEC codes are not to be considered.

E. SITE DESCRIPTION

1. Sites Operating Systems

Unlike AIR, ACIM specifies that only organizational level sites may operate systems. This also means that all

user sites must have an 'O' designation and must be within the lowest echelon level.

The method this thesis uses to allow a PIMA site to operate systems, as in AIR, is to insert a dummy site under the intermediate site representing the operational capability of the PIMA. To correctly model this arrangement, the dummy site is designated with 'O' to allow systems to operate from it but the dummy site is defined without repair or stockage capability. Also the replacement item lead time from the actual PIMA facility is given as zero so that items are forced to be stocked and repaired at the PIMA site but without causing an increase in MSRT for the dummy operational site.[10]

2. Site System Operational Usage Differences

In earlier versions of ACIM, there was no way to distinguish differences in average system usage for the different sites. In the NPS installed version, a capability exists for this designation. On each input data card designating the characteristic parameters of a site, there is a data field for an entry called the operational level. A more appropriate name for this data entry is system usage. If nothing is put in this field, a default value of 1 is used. System usage for a site is expressed as a decimal

---

[10] This arrangement appeared to work fairly well, but due to an apparent bug in ACIM, some items were allowed to be stocked at the dummy site. This was handled by combining inventories for the PIMA and dummy site.

fraction derived by dividing the average monthly individual system operational time at the site by the overall average monthly individual system operational time. This input field enables AIR site differences involving system usage to be represented in ACIM.

The procedural steps for calculating system usage at each site are as follows:

First calculate total annual system operational hours using Equation (7.3). Next, calculate the average overall monthly system operational time per system,

$$\text{AVEH} = \frac{\text{THOUR}}{\text{N} \times 12}, \tag{7.8}$$

where:

N = the total number of systems (the sum of all N(i)).

Calculate AVE(i) = average monthly system operational time at each site (i),

$$\text{System Usage for Site (i)} = \frac{\text{AVE(i)}}{\text{AVEH}}. \tag{7.9}$$

The system usage fraction for each site is multiplied by the item BRF rates to determine the individual site demand rates for each item.

3. Steady State Site Representation

The AIR inputs specify how systems are deployed annually to different sites for consideration in calculating system life support costs. In order to do this, the same systems might be represented more than once for different sites with the deployment factor D(i) showing percentage of annual time the system is operated at each different site (i). As long as the deployment factors pertaining to each individual system add together for a total annual deployment of less than or equal to one, then model logic is maintained.

For modeling with ACIM, a different approach has to be taken. All sites cannot be represented simultaneously, but as an expected steady state of operation for all the systems throughout the Navy. This steady state may be thought of as a snapshot of normal system operation throughout the Navy at any instant in time.

An example of this steady state is the aircraft carrier situation on the east coast of the USA. There are six carriers available, but at any given time only three are operationally deployed. The east coast carrier situation would, therefore, have to be modeled as three and the ACIM derived inventory requirements would have to be transferred to the other three carriers when they deploy or are allocated through calculations outside the model. This is because for the steady state situation, the east coast intermediate supply facilities only support the activities of the three deployed carriers.

It should be noted that the systems usually onboard the nondeployed carriers might be temporarily operating at a Naval Station. While ashore, the systems are often operated at a reduced monthly rate. The steady state modeled by ACIM has to reflect a shore-based organizational site which supports the three non-carrier deployed squadrons. This site is often a PIMA. Here the PIMA operational level is useful for defining the reduced system operation rate for the squadrons temporarily based ashore.

4. Site Comparison Levels

The ACIM version implemented at NPS has the capability of modeling ten different sites in the support organization. Any user requiring additional sites to be considered will have to adapt the JCARD input format to reflect this. This is easily done with some minor programming changes. The NPS implementation was done to enable 80 column input card usage while maintaining the capability to input the parameters required for the other possible ACIM comparison policies. Appendix A illustrates required JCARD format for the NPS version.

5. ECM Considerations

Unlike the AIR model, ACIM is unable to consider beyond the capability of maintenance rates for any item at the various repair facilities. The analyst utilizing ACIM should be aware that an item sent to the SM&R designated location for repair is modeled as either being repaired or

scrapped at that site. The model does not consider sending the item to a higher repair-capable site if the fault is one which is BCM for the designated site. An analyst concerned that this ACIM shortcoming will detrimentally influence his desired results might consider redetermining the LOR code or adjusting the item repair scrap rate. This might require reutilization of AIR to evaluate other repair alternatives.

VIII. ILLUSTRATION EXAMPLE

The chapter describes the example scenario used to illustrate the feasibility of using the ACIM model to determine the provisioning required to attain a specified level of system operational availability for an LOR policy evaluated by AIR.

A. SYSTEM COMPONENT BREAKDOWN AND DESCRIPTION

The illustration system is a three indenture-level hierarchy of items. Table IV lists all pertinent system characteristics data used in both AIR and ACIM model inputs.

All items in the system have a false removal rate of zero and a false removal detection rate of one.

The system MTTR is 0.07 of a day (approximately 1 hour and 45 minutes). This is the fraction of a day required to fault isolate to a WRA, remove and replace the defective WRA, and verify the system ready for operational use.

The item names in Table IV illustrate the indentured hierarchical relationship of the items within the system.

A cost for the entire system is not given because it is not an input requirement for either model, nor is it germane to the analysis. LOR and provisioning policies do not depend on total system price unless the price is so small that the cost-effective maintenance policy would be to discard the whole system upon failure.

TABLE IV

Illustration System Item Breakdown and Description

REF NUM	PART NAME	POP	UNIT COST	MTBF	BRF	SCR	SM&R
000	EXAMPLE SYSTEM	1		30	12.9229		
100	WRA-1	3	19875	920	0.4217	0.10	OO
110	SRA-1	1	7020	2415	0.1607	0.10	OH
120	SRA-2	4	2325	8333	0.0466	0.10	OH
130	SRA-3	1	3485	5375	0.0722	0.20	OH
200	WRA-2	6	11595	475	0.8168	0.10	OO
210	SRA-4	1	4020	2415	0.1607	0.10	OH
240	SRA-5	2	3770	1190	0.3261	0.10	OH
300	WRA-3	2	16250	775	0.5006	0.10	OO
310	SRA-6	2	4020	2415	0.1607	0.10	OH
350	SRA-7	2	3960	4540	0.0855	0.10	OH
400	SRA-4	7	8040	1390	0.2791	0.10	OD
500	SRA-5	2	36535	315	1.2317	0.10	OO
560	SRA-8	3	6105	1470	0.2639	0.10	OH
570	SRA-9	1	7005	5000	0.0776	0.10	OH
580	SRA-10	2	5575	2275	0.1705	0.18	OH
600	WRA-6	1	55775	290	1.3379	0.10	OO
660	SRA-11	2	8105	1470	0.2639	0.10	OH
690	SRA-12	2	19775	625	0.6208	0.10	OH
691	SUBSRA-1	1	5890	4150	0.0935	0.15	HX
692	SUBSRA-2	3	4345	2150	0.1805	0.10	HD

where:

POP = Number of the item in the system
UNIT COST = The cost in dollars of one item
MTBF = mean time before failure
BRF = best replacement factor
SCR = item scrap rate during repair
SM&R = The maintenance portion of the SM&R code
O = organizational level
H = shore-based intermediate activity
D = depot
X = discard

The model assumptions do not require a scrap rate or SM&R code be assigned to the system.

B. HYPOTHETICAL NAVY MAINTENANCE SUPPORT ORGANIZATION

This section describes a hypothetical Navy three-echelon maintenance and support organization which supports the illustration system in this thesis. Actual sites were used in this example for greater understanding and appreciation of transit distances and supply lead times. The site parameters used in this example are for illustration purposes only and are not actual data.

The Naval Air Systems Command Avionic Equipment Default Data Guide [Ref. 12] provided a basis for specifying inter-site lead times which were adjusted to reflect different distances between sites.

At the organizational level, there are both ship and land-based sites operating the equipment. Six operational squadrons are homebased at NAS Cecil Field on the east coast and six operational squadrons are homebased at NAS North Island on the west coast. An operational squadron is composed of ten systems. Each operational squadron annually deploys on a ship 50 percent of the time with the remaining 50 percent spent operating from the homebase. Actual ship deployment is rotated among the six squadrons on each coast so that three squadrons constantly remain at each homebase NAS. On both coasts, two of the shipboard squadrons are considered forward-deployed with the third shipboard

squadron in a working-up predeployment status. A squadron returns from forward deployment upon onstation relief by the predeployment squadron. As a squadron returns to its homebase, another squadron commences predeployment shipboard operations.

At NAS North Island, there is a permanently established training squadron consisting of 15 systems.

Per system monthly operating hours are as follows:

Training squadron	30 hours
Homebased squadron	25 hours
Shipboard squadron	40 hours

Each NAS actually is a PIMA because of its expanded repair and spare parts inventory capability. The PIMA portion of each NAS is considered the second echelon of support even though it is co-located at an operational site.

The NAS Cecil Field PIMA supports all east coast squadrons whether they are shore-based or ship-based. The NAS North Island PIMA supports only the training squadron, shore-based squadrons, and the predeployed ship-based squadron. Once squadrons on the west coast deploy forward, their PIMA requirements are supported by the facility at NAS Cubi Point, Philippines. There are no locally operated systems at NAS Cubi Point.

The highest echelon is the depot which is represented by the Naval Air Rework Facility (NARF), Alameda, California

and the Naval Supply Center (NSC), Oakland, Ca. These two facilities are treated as one because the lead time to each PIMA from the NARF for reissued repairables is virtually the same as the lead time to each PIMA from the supply center for replacement of consumed items. There are no systems operated at either the NARF or the NSC.

Analysis is facilitated when the separate squadrons at an NAS are aggregated into one squadron. The system monthly hours are weighted by the number of systems in each squadron type to arrive at an average monthly system hour usage for each site.

Table V illustrates the AIR inputs used to model the support organization in this scenario.

Table VI illustrates the ACIM input data used to model the sample scenario support organization, as depicted in Figure 2.3.

C. ACIM COMPARISON OF AIR PROVISIONING

1. Discussion of Output Format

The following tables summarize the ACIM comparison of AIR provisioning for each site. The first ACIM run was the least cost provisioning resulting in 95 percent system A_o or the maximum attainable A_o for the site if it is lower than 95 percent. Since the first ACIM run (ACIM(1)) resulted in different provisioning for each carrier site, a second ACIM run (ACIM(2)) was initiated with each carrier having an

TABLE V

AIR Support Organization Data

SITE	NAME	ECH	DAYS STCK	REP CYC	NUM SITE	NUM SYS	MON HRS	DEPL FACT	DIST-RP ID	PCT
1	DEPOT	4	318		1	0				
2	PIMA, CF	3	30	7	1	30	25	1.0	1	1.0
3	CV, EAST	1	90	7	6	10	40	0.5	1	1.0
									2	1.0
4	PIMA, NI	3	30	7	1	45	27	1.0	1	1.0
5	PIMA, CUBI	3			1	0			1	1.0
6	CV, WSTPAC	1	90	7	6	10	40	0.5	1	1.0
									4	.33
									5	.67

where:

ECH describes the site type

1 = Ship-based operational site
2 = Land-based operational site
3 = PIMA site (may operate systems)
4 = Depot

DAYS STK is the required days stock
For operational sites, DAYS STK = designated self-supporting period
For Depot, DAYS STK = 273 days procurement lead time plus 45 days buffer stock

REP CYC is the repair cycle at an operational site
For faulty items sent to higher echelon repair sites for AIR system stock calculations, the repair cycles are as follows:

Ship - PIMA	70
Ship - Depot	100
PIMA - Depot	60
Ship - PIMA - Depot	116

NUM SITE = number of sites represented by site type

NUM SYS = number of systems at a site

MON HRS = the system monthly operating hours at the site

DEPL FACT = annual deployment for the site expressed as a fraction of ayear.

TABLE V (CONT.)

DIST-RP describes how repairables at each site are sent to higher echelons.

ID = higher echelon repair site ID number

PCT = percent repairables sent to that site ID. The PCTs for each higher echelon added together must sum to 1.0

TABLE VI

ACIM Support Organization Data

SITE	NAME	ECH	S	R	LEAD TIME	REP CYC	NUM SITE	NUM SYS	SYSTM USAGE
1	DEPOT	D	X	X	273	37	1		
2	PIMA, CF	I	X	X	10	7	1		
2A	SQDN, CF	O			0		1	30	0.773
3	CV, EAST	O	X	X	25	7	3	10	1.240
4	PIMA, NI	I	X	X	9	7	1		
4A	SQDN, NI	O			0		1	45	0.828
5	CV, WEST	O	X	X	10	7	1	10	1.240
6	PIMA, CUBI	I	X	X	13	7	1		
5A	CV, WSTPAC	O	X	X	15	7	2	10	1.240

Note: Sites 2A and 4A are dummy sites, see Section VII.E
Site 5A is part of site 5 in the AIR data

where

ECH describes the type of site

0 = organizational site
I = intermediate site
D = depot site

R - an X in this column indicates the site has a repair capability

S - an X in this column indicates the site has an inventory stockage capability

LEAD TIME - the average time required to receive supply items from the next higher echelon

REP CYC - the average repair cycle time at the site

NUM SITE - the number of sites this site type represents

NUM SYS - number of systems at each site

SYSTM USAGE - fraction of monthly system operating time at the site compared to the overall average

identical fixed inventory. This fixed carrier inventory was arbitrarily chosen from the first run ACIM provisioning for east coast carriers because this carrier location represented the larger number of carriers.

With all carrier provisioning fixed, only the PIMA's and the Depot provisioning had to be determined through ACIM optimization. The purpose behind this procedure was to standardize the carrier inventory.

In the following tables, the following output data is given. The MSRT is the mean supply response time for the item at the site resulting from either a local or lower echelon demand. QTY is the amount of the item stocked at the site for the respective policy.

Below this data are some item stockage data. The number of items excluded by SM&R code for stockage is given. The number of stockage candidates is the total number of system items minus the number of items excluded by their SM&R code. The number of items nonstocked is the number of items which were stockage candidates at the site, but were not stocked by the respective policy. The number of units stocked is the sum of the number of each item stocked at the site.

The stocked investment is the dollar cost of the inventory suggested by each policy for the site.

The performance factors under each site measure the inventory as a whole at the site. Site inventory performance

considers all demands from lower echelon sites supported by the facility and all locally generated item demands. The fill rate is the expected fraction of demands on inventory at the site which are immediately filled from stocks on-hand. The expected units short is the sum, over all stockage candidates, of the number of units demanded but not immediately available from stock. The backorder days is the sum, over all items in the system, of the number of units demanded at the site but not immediately available from stock multiplied by the expected length of time each backorder exists before a replacement item becomes available thro-gh repair or resupply. The expected units short and the backorder days are referenced to unfilled demands occurring during 90 days (CNO designated self-supporting period) for an organizational site and during the respective resupply lead time from the next higher echelon for non-organizational sites.

Only sites which operate the system have availability statistics listed in the following tables. The achieved A_o is the ACIM calculated operational availability at the site for the respective policy. The maximum A_o is the ACIM calculated maximum operational availability which could be achieved at the site. The maximum A_o is similar to the inherent availability except that ACIM calculates A_o based on N systems at the site as explained in Section VII.B.1.

TABLE VII

Depot Provisioning Comparisons

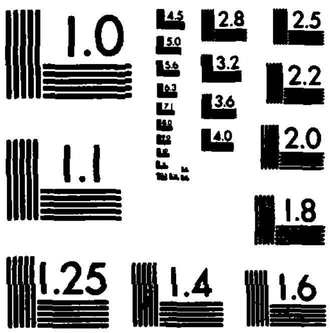
REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	0.0636	15	0.4341	13	0.4341	13
110	SRA-1	2.1235	6	92.8968	2	170.9251	1
120	SRA-2	3.6143	6	25.1885	4	25.1885	4
130	SRA-3	35.1256	5	62.8274	4	62.8274	4
200	WRA-2	0.0000	59	0.0024	35	0.3573	32
210	SRA-4	0.3828	11	45.1436	5	24.9053	6
240	SRA-5	0.0000	42	17.0098	21	17.0098	21
300	WRA-3	0.1807	12	0.1807	12	0.5004	11
310	SRA-6	2.2756	7	34.7092	4	15.5719	5
350	SRA-7	9.3856	4	26.4893	3	26.4893	3
400	WRA-4	1.2759	37	0.0698	43	1.8045	36
500	WRA-5	0.0000	30	0.3918	21	0.0944	23
560	SRA-8	0.0888	17	14.4852	10	24.1373	9
570	SRA-9	19.1711	2	83.7346	1	272.9998	0
580	SRA-10	16.8299	14	24.7764	13	16.8299	14
600	WRA-6	0.0403	16	0.6693	13	0.6693	13
660	SRA-11	2.8482	6	50.3807	3	21.8853	4
690	SRA-12	0.1452	14	29.6795	7	29.6795	7
691	S-SRA-1	272.9998	0	24.1350	19	31.6493	18
692	S-SRA-2	5.0809	19	2.8592	21	3.8598	20

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	0	0	0
# of Stock Candidates	20	20	20
# Items Stocked	19	20	19
# Items Nonstock	1	0	1
# Units Stocked	322	254	244
Investment			
Stocked	4,387,075	3,368,165	3,325,275
Performance			
Fill Rate	0.879	0.946	0.930
Exptd Unts Sht	125.520	53.764	71.215
Backorder Days	6568.022	2946.541	3788.287

AD-A137 507 COMBINING A LEVEL OF REPAIR MODEL WITH AN AVAILABILITY CENTERED PROVISIONING MODEL FOR LOGISTIC SUPPORT ANALYSIS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA H J WATRAS SEP 83 2/2

UNCLASSIFIED F/G 15/5 NL

END
FILMED
3-84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE VIII

NAS CECIL PROVISIONING COMPARISONS

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	0.5086	1	0.0000	3	0.0000	3
110	SRA-1	1.7379	1	4.1316	1	7.2011	1
120	SRA-2	1.9973	1	0.5776	2	0.5776	2
130	SRA-3	3.2247	1	5.7780	1	5.7780	1
200	WRA-2	0.0215	3	0.0000	5	0.0001	4
210	SRA-4	1.2231	2	2.0034	2	3.9708	1
240	SRA-5	0.2667	7	0.8572	6	1.4941	5
300	WRA-3	0.4148	1	0.0000	3	0.0000	3
310	SRA-6	0.4931	2	0.8345	2	0.6208	2
350	SRA-7	1.4218	1	1.7330	1	1.7330	1
400	WRA-4	1.8102	4	0.0000	10	0.0000	13
500	WRA-5	0.0618	2	0.0036	3	0.0032	3
560	SRA-8	0.7712	3	0.3689	4	1.1307	3
570	SRA-9	0.7837	1	1.4922	1	4.6595	1
580	SRA-10	4.7461	1	0.8538	3	4.7461	1
600	WRA-6	0.5344	1	0.0000	3	0.0000	3
660	SRA-11	1.8886	1	0.7588	2	0.4979	2
690	SRA-12	33.4004	2	2.0223	3	0.7161	4
691	S-SRA-1	250.4739	1	14.5623	1	7.7877	2
692	S-SRA-2	1.2316	4	1.8790	3	2.2690	3

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	0	0	0
# of Stock Candidates	20	20	20
# Items Stocked	20	20	20
# Items Nonstock	0	0	0
# Units Stocked	40	59	58
Investment			
Stocked	392,995	724,105	737,250
Performance			
Fill Rate	0.889	0.938	0.871
Exptd Unts Shrt	5.628	3.680	6.659
Backorder Days	21.712	12.151	25.209
Operational Avail			
Achieved	0.70778	0.94493	0.94493
Maximum	0.94545	0.94545	0.94545

TABLE IX

East Coast Carrier Provisioning Comparisons

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	1.5755	1	0.0281	3	0.0316	3
110	SRA-1	4.2114	1	4.9499	1	5.9721	1
120	SRA-2	0.6386	2	4.4163	1	4.4163	1
130	SRA-3	2.2371	1	2.6471	1	2.6471	1
200	WRA-2	0.2170	3	0.0080	6	0.0096	6
210	SRA-4	0.2420	3	7.6975	1	8.7255	1
240	SRA-5	0.0003	11	2.2833	4	2.4804	4
300	WRA-3	1.1010	1	0.0906	2	0.0903	2
310	SRA-6	0.6877	2	0.7136	2	0.6973	2
350	SRA-7	3.0166	1	3.0852	1	3.0852	1
400	WRA-4	0.0162	6	0.0106	6	0.0172	6
500	WRA-5	2.6729	1	0.0512	3	0.0550	3
560	SRA-8	0.1625	4	0.7462	3	0.8247	3
570	SRA-9	25.7837	0	1.4376	1	1.7940	1
580	SRA-10	1.1689	2	0.7944	2	1.1689	2
600	WRA-6	2.8205	1	0.2289	2	0.2214	2
660	SRA-11	4.6109	1	4.2532	1	4.1725	1
690	SRA-12	6.2823	3	2.4543	2	2.1789	2
691	S-SRA-1	0.0000	0	0.0000	0	0.0000	0
692	S-SRA-2	0.0000	0	0.0000	0	0.0000	0

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	2	2	2
# of Stock Candidates	18	18	18
# Items Stocked	17	18	18
# Items Nonstock	1	0	0
# Units Stocked	44	42	42
Investment			
Stocked	395,145	559,145	559,145
Performance			
Fill Rate	0.776	0.598	0.598
Exptd Unts Short	18.752	26.544	26.544
Backorder Days	778.426	1393.394	1393.394
Operational Avail			
Achieved	0.65572	0.95078	0.95007
Maximum	0.97018	0.97018	0.97018

TABLE X

NAS North Island Provisioning Comparisons

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	0.0108	2	0.0000	3	0.0000	3
110	SRA-1	1.5960	1	11.7448	0	15.6462	0
120	SRA-2	1.8389	1	8.3594	0	8.3594	0
130	SRA-3	2.9201	1	19.9655	0	19.9655	0
200	WRA-2	0.0000	7	0.0000	4	0.0001	4
210	SRA-4	1.1384	2	9.3572	0	8.3453	0
240	SRA-5	0.4041	6	7.9505	0	7.9505	0
300	WRA-3	0.0071	2	0.0000	3	0.0000	3
310	SRA-6	2.0230	1	2.8985	1	7.8786	0
350	SRA-7	1.3017	1	8.4245	0	8.4245	0
400	WRA-4	0.1795	6	0.0001	8	0.0004	10
500	WRA-5	0.0016	3	0.0003	3	0.0002	3
560	SRA-8	1.7028	2	0.8464	3	8.3069	0
570	SRA-9	0.7128	1	11.2867	0	20.7500	0
580	SRA-10	4.4637	1	2.1200	2	10.3894	0
600	SRA-6	0.0120	2	0.0000	3	0.0000	3
660	SRA-11	1.7369	1	2.8962	1	8.1943	0
690	SRA-12	31.5904	2	11.3006	0	20.3733	0
691	S-SRA-1	246.5237	1	11.5871	1	40.6492	0
692	S-SRA-2	0.8264	4	1.3509	3	7.5338	1

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	0	0	0
# of Stock Candidates	20	20	20
# Items Stocked	19	11	7
# Items Nonstock	1	9	13
# Units Stocked	47	35	27
Investment			
Stocked	569,995	546,520	516,430
Performance			
Fill Rate	0.889	0.475	0.088
Exptd Units Shrt	11.615	9.941	16.175
Backorder Days	17.298	81.562	141.659
Operational Avail			
Achieved	0.88314	0.91535	0.91535
Maximum	0.91546	0.91546	0.91546

TABLE XI

West Coast Carrier Provisioning Comparisons

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	0.9098	1	0.0913	3	0.0140	3
110	SRA-1	0.8444	1	21.7448	0	3.8921	1
120	SRA-2	0.0593	2	2.3561	1	2.3561	1
130	SRA-3	0.4829	1	2.5131	1	2.5131	1
200	WRA-2	0.1511	3	0.0166	5	0.0014	6
210	SRA-4	0.0099	3	4.2032	1	3.8063	1
240	SRA-5	0.0000	11	1.8130	3	0.6050	4
300	WRA-3	0.7011	1	0.0684	2	0.0539	2
310	SRA-6	0.0809	2	1.3601	1	0.2530	2
350	SRA-7	0.5778	1	1.5026	1	1.5026	1
400	WRA-4	0.0000	6	0.0049	4	0.0035	6
500	WRA-5	1.7548	1	0.0339	3	0.0305	3
560	SR8	0.0046	4	0.3181	2	0.2403	3
570	SRA-9	10.7138	0	0.9349	1	1.9255	1
580	SRA-10	0.1541	2	1.2744	1	0.4092	2
600	WRA-6	1.2992	1	0.0286	3	0.2355	2
660	SRA-11	0.9429	1	1.1311	1	2.1966	1
690	SRA-12	2.1875	3	6.1470	1	4.6193	2
691	S-SRA-1	0.0000	0	0.0000	0	0.0000	0
692	S-SRA-2	0.0000	0	0.0000	0	0.0000	0

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	2	2	2
# of Stock Candidates	18	18	18
# Items Stocked	18	17	18
# Items Nonstock	0	1	0
# Units Stocked	44	34	42
Investment			
Stocked	395,145	540,980	559,145
Performance			
Fill Rate	0.776	0.466	0.598
Exptd Units Shrt	18.752	30.794	26.544
Backorder Days	778.426	1851.102	1393.394
Operational Avail			
Achieved	0.75483	0.95834	0.95521
Maximum	0.97018	0.97018	0.97018

TABLE XII

NAS Cubi Point Provisioning Comparisons

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	13.0636	0	13.4341	0	13.4341	0
110	SRA-1	7.4062	0	1.7010	1	15.8463	0
120	SRA-2	7.4807	0	1.0304	1	8.5594	0
130	SRA-3	15.2251	0	2.3610	1	20.7654	0
200	WRA-2	13.0000	0	13.0024	0	13.3573	0
210	SRA-4	7.3191	0	2.0532	1	8.5453	0
240	SRA-5	7.3000	0	2.0109	2	8.1505	0
300	WRA-3	13.1807	0	13.1807	0	13.5004	0
310	SRA-6	7.4138	0	1.2966	1	8.0786	0
350	SRA-7	7.7693	0	8.6245	0	8.6245	0
400	WRA-4	14.2759	0	2.6322	2	7.5988	1
500	WRA-5	13.0000	0	13.3918	0	13.0944	0
560	SRA-8	7.3044	0	2.2438	1	8.5069	0
570	SRA-9	8.2586	0	11.4867	0	20.9500	0
580	SRA-10	11.1094	0	2.5283	1	11.1094	0
600	WRA-6	13.0403	0	13.6693	0	13.6693	0
660	SRA-11	7.4424	0	1.2711	1	8.3943	0
690	SRA-12	61.9611	0	3.1871	1	12.6439	0
691	S-SRA-1	285.9993	0	6.2481	1	12.3102	1
692	S-SRA-2	18.0809	0	1.4950	2	2.6392	2

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	0	0	0
# of Stock Candidates	20	20	20
# of Items Stocked	0	13	3
# Items Nonstock	20	7	17
# Units Stocked	0	16	4
Investment Stocked	0	98,630	22,620
Performance			
Fill Rate	0.000	0.770	0.220
Exptd Units Shrt	7.250	2.915	6.156
Backorder Days	94.253	21.693	73.523

TABLE XIII

West Pacific Carrier Provisioning Comparisons

REF NUM	PART NAME	AIR MSRT	AIR QTY	ACIM(1) MSRT	ACIM(1) QTY	ACIM(2) MSRT	ACIM(2) QTY
100	WRA-1	1.4697	1	0.1212	2	0.0331	3
110	SRA-1	3.0113	1	1.7137	1	5.5107	1
120	SRA-2	0.3752	2	0.1427	2	3.7833	1
130	SRA-3	2.5556	1	0.8644	1	3.5406	1
200	WRA-2	0.2292	3	0.0087	5	0.0056	6
210	SRA-4	0.1348	3	0.4628	2	6.0137	1
240	SRA-5	0.0001	11	0.1355	5	1.5524	4
300	WRA-3	1.0477	1	0.1153	2	0.0899	2
310	SRA-6	0.4797	2	2.1300	1	0.5207	2
350	SRA-7	2.2650	1	2.4320	1	2.4320	1
400	WRA-4	0.0273	6	0.0094	5	0.0057	6
500	WRA-5	2.6011	1	0.0447	3	0.0539	3
560	SRA-8	0.0868	4	0.1942	3	0.5753	3
570	SRA-9	23.2585	0	1.4371	1	2.6129	1
580	SRA-10	0.8163	2	0.2667	2	0.8163	2
600	WRA-6	4.9030	1	0.1258	2	0.2337	2
660	SRA-11	3.2776	1	0.1336	2	3.5461	1
690	SRA-12	13.7806	3	0.8597	2	2.6025	2
691	S-SRA-1	0.0000	0	0.0000	0	0.0000	0
692	S-SRA-2	0.0000	0	0.0000	0	0.0000	0

	AIR	ACIM(1)	ACIM(2)
Total Number of Items	20	20	20
SM&R Excluded	2	2	2
# of Stock Candidates	18	18	18
# Items Stocked	17	18	18
# Items Nonstock	1	0	0
# Units Stocked	44	42	42
Investment			
Stocked	395,145	533,835	559,145
Performance			
Fill Rate	0.776	0.639	0.598
Exptd Units Shrt	18.752	26.253	26.544
Backorder Days	778.426	1250.234	1393.394
Operational Avail			
Achieved	0.62109	0.95110	0.95090
Maximum	0.97018	0.97018	0.97018

Tables IX, XI, and XIII reflect the performance and provisioning levels of a single carrier only. The results must be applied to the actual number of carriers that the site data represents.

2. Discussion of Results

The tabulated results indicate that, generally, A_o is not directly related to the number of units stocked, fill rate, expected units short, or total number of backorder days at a site. The ACIM fill rate at all organizational sites except for NAS Cecil Field was less than the fill rate achieved by AIR. Of particular note is the extremely low fill rate at NAS North Island (0.088 for ACIM(2)) which was still accompanied by a local A_o of 0.915. This can be explained by stocking WRA's almost exclusively at the site. The low fill rate is mostly attributable to the lack of lower indentured items in stock at the site, but stockage effectiveness in terms of A_o is compensated by the greater quantity of WRA's stocked.

ACIM decreased the number of items stocked and the inventory investment at the depot for both ACIM runs. This was accompanied by a much higher inventory investment at carrier sites through both ACIM and AIR provisioned approximately the same number of units at these sites.

The difference in ACIM(1) and ACIM(2) is interesting. ACIM(2) actually changed only the inventories of the West Coast and WESTPAC carriers, but the effect on inventory

stockage is also seen on the East Coast at NAS Cecil Field even though the East Coast does not support the West Coast carriers. This resulted because the fixing of carrier inventory forced a greater quantity of spare items to be stocked at the organizational level on the West Coast. This lessened the demand on the two West Coast PIMA's and the depot. The most significant difference in stockage at NAS Cecil Field between ACIM(1) and ACIM(2) is that ACIM(2) stocked three more items of WRA-4. WRA-4 was maintenance coded to be discarded upon removal at the organizational level.

Nielsen and Shahal [Ref. 11] documented similar results in a comparison of AIR provisioning with that of OPUS-VII, a provisioning model developed for the Swedish military. Though their example system and hypothetical support organization are not the same as those in the illustration example in this thesis, the results were comparable.

Table XIV compares the magnitude of difference for the Nielsen and Shahal thesis to the results of this thesis.

TABLE XIV

Results of Comparing AIR Provisioning to ACIM and OPUS-VII

	This Thesis		Nielsen and Shahal	
	AIR	ACIM(2)	AIR	OPUS-VII
A_o	0.621-0.883	0.915-0.955	0.56	0.97
Inventory Cost	$10,091,805	$11,311,315	$901,930	$527,965

Because ACIM calculates a system A_o for each organizational site Table XIV presents the range of A_o calculated for all sites by ACIM. The A_o formula in OPUS-VII is unlike that of ACIM and calculates an overall system A_o. Therefore, the Nielsen and Shahal results reflect a single A_o value derived from OPUS-VII. The various system operating sites are presented with the Nielsen and Shahal results as a ratio of AIR provisioned A_o divided by the respective provisioning model (ACIM or OPUS-VII) A_o.

Table XV indicates that ACIM evaluates the AIR provisioning of land-based sites more favorably. The two possible reasons are :

(1) Land-based sites support greater number of systems;

(2) Land-based sites have shorter supply lead times from the echelon above them.

TABLE XV

Further Comparison of AIR Provisioning

	AIR/Comparison Ratio
NAS Cecil	0.749
East Coast Carriers	0.690
NAS North Island	0.965
West Coast Carriers	0.790
WESTPAC Carriers	0.653
Neilsen and Shahal Results	0.573

Table XV also seems to indicate that OPUS-VII evaluates AIR provisioning more unfavorably than ACIM.

The cost comparison in Table XIV is significant. Nielsen and Shahal discovered in their example that OPUS-VII eliminated many of the expensive WRA's placed by AIR in system stock. OPUS-VII reallocated many WRA's placed by AIR at the organizational level to the intermediate level. The final result was a dramatically increased overall system availability which required a less expensive inventory.

When Nielsen and Shahal used OPUS-VII to evaluate the AIR provisioning without reallocation, the model concluded that many of the WRA's stocked by AIR could be eliminated without affecting the overall system availability.

3. Summary of Results

The initial observation of the tabulated analysis results shows that use of the Aviation Supply Office provisioning guidelines by AIR in the calculations of site inventories results in system operational availability which varies from site to site. The resulting system A_o as a function of the AIR suggested provisioning levels at each site cannot be predetermined. Inspection of the tables, especially of the two ACIM runs, reveals that a change in the provisioning at one site has a rippling effect on the mean supply response time of items demanded by lower echelons within the support organization.

During the iterative process evaluating the placement of items at each site, ACIM placed many more items at intermediate supply sites than did AIR. The items placed at intermediate sites sometimes benefited the operational sites more than placement at the organizational site because MSRT was reduced more effectively throughout the whole support organization. AIR lacks any capability for the consideration of item placement at intermediate sites for the mutual benefit of many operational site.

The ACIM algorithm appears to favor stocking higher indentured assemblies. This results in a higher overall inventory cost, but it is accompanied by a higher expected system operational availability at each site. Because more higher indentured assemblies are stocked, the total number of units stocked is less than the AIR suggested provisioning at most sites. Also the stocking of higher indentured assemblies discounts the value of fill rate and total backorder days because these would tend to be concentrated in the lower indentured item demands.

For this system LOR policy, AIR calculated that the inventory costs associated with its provisioning would account for 11.5 percent of life support costs. By allocating approximately 12 percent more (for ACIM(2)) to provisioning, the expected system operational availability can be raised substantially at each site, as illustrated in Table XVI. This would equate to an increase of less than 2 percent to the life support cost.

TABLE XVI

Comparison Summary of Provisioning Policies

	AIR	ACIM(1)	ACIM(2)
Total Inventory Cost	10,091,805	10,777,360	11,311,315
Site Operational Availability			
NAS Cecil Field	0.70778	0.94493	0.94493
East Coast Carriers	0.65572	0.95078	0.95007
NAS North Island	0.88314	0.91535	0.91535
West Coast Carriers	0.75483	0.95834	0.95521
WESTPAC Carriers	0.62109	0.95110	0.95090

The total inventory costs listed in Table XVI reflect the data presented in Tables VII through XIII. The data from the tables describing aircraft carrier sites have to be multiplied by the number of carriers represented for appropriate inclusion in total inventory cost. The total inventory costs also assume that a carrier which is represented but not actively deployed, still maintains an inventory for the system.

IX. CONCLUSIONS

The AIR and ACIM models may be effectively used in conjunction with each other for the purpose of logistic support analysis. Starting in the early design phase, the combination of the models may be continually employed to influence the final system design so that the optimal integrated system is attained. As an integrated system, the prime mission system is considered together with its logistic support policy as one system.

Once the system is in the use period of its life cycle, the models may continue to be used for the purpose of ongoing logistic management evaluation and review. The emphasis of the ongoing evaluation and review is to insure that the logistic support policy for the system cost-effectively provides system support requirements in order that the desired level of system availability is attained.

The AIR model is particularly useful in the area of system maintenance engineering. The LSC information provided by AIR is useful to an analyst in deciding on LOR policy on the basis of least cost. An analyst must be judicious in the use of the AIR model, however. The AIR model inadequately estimates inventory requirements at all support sites and, therefore, all inventory related costs are underestimated.

For a more accurate estimate of the inventory related costs, a provisioning model such as ACIM should be utilized. ACIM is useful for analysis involving the supply support area of logistics management. ACIM is able to provision for a multi-indentured system which is supported through the typical U.S. Navy multi-echelon support organization.

ACIM can be used to establish the least cost provisioning policy to achieve a specified system operational availability. Alternatively, ACIM can be used to achieve the minimum supply response time under the constraint of a fixed budget allocated for spare parts inventory.

The inputs required for ACIM are not directly compatible to the AIR inputs. With an understanding of the analysis situation, most analysts should be able to easily make the transformation of data inputs for use in either model during any analysis requiring the use of both models.

APPENDIX A

NPS IMPLEMENTED JCARD FORMAT

The following is a brief description of the modified input format for the optional data cards which are referred to as the JCARDS. These cards are referred to as JCARDS because the character in the first column is 'J' to identify it as such. This modification applies only to the NPS implemented version of ACIM. This modification was undertaken to enable the existing ACIM program input requirements to be compatible with the IBM 3033 installed PL/1 at NPS. Also, in addition, this modification allowed for ten different sites in a support organization when using ACIM to compare user inserted site provisioning stocks.

The following JCARD format is further explained in the ACIM 2.0 Handbook [Ref. 14].

Cols	Data Element	MODE	Unit
1	Format ID (J)	A	
2-11	Item Ref #	AN	
12-17	User MSRT	R	Days
18-21	Procurement Lead Time	R	Days
22-24	Depot Repair Cycle	R	Days
25-28	Scrap Rate	R	Fraction
29-34	Annual Wholesale Demand	I	Units Per Year
35-38	Wholesale Stock Level	I	Units

Cols	Data Element	MODE	Unit
	Specified Stock Levels for Specific Site		
40-43	Site 1	I	Units
44-47	Site 2	I	Units
48-51	Site 3	I	Units
52-55	Site 4	I	Units
56-59	Site 5	I	Units
60-63	Site 6	I	Units
64-67	Site 7	I	Units
68-71	Site 8	I	Units
72-75	Site 9	I	Units
76-79	Site 10	I	Units

where:

A signifies latter character;

AN signifies alpha-numeric character;

R signifies a real number;

I signifies an integer number.

LIST OF REFERENCES

1. Kline, M.B., Logistics Engineering, Course Notes, Naval Postgraduate School, Monterey, California, 1980.

2. Blanchard, B.S., Logistics Engineering and Management, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1981.

3. Department of Defense, Military Standard 1388/1a: Logistics Support Analysis, Washington, D.C., 1983.

4. Department of the Navy, Military Standard 1390B: Level of Repair, Washington, D.C., 1976.

5. Department of the Navy, OPNAV Instruction 3000.2: Operational Availability of Weapon Systems and Equipments; Definitions and Policy, Washington, D.C., 1981.

6. Department of Defense, Military Standard 721B: Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety, Washington, D.C., 1970.

7. Guion, S.W., Provisioning, COSALs, AVCALs, OA 4501 Course Notes, Naval Postgraduate School, Monterey, California, 1982.

8. Department of the Navy, OPNAV Instruction 4441.12A: Supply Support of the Operating Forces, Washington, D.C., 1973.

9. CACI, Inc., ACIM: An Availability Centered Inventory Model, User's Manual, Arlington, Virginia, 1981.

10. Naval Air Systems Command, MOD III Level of Repair Model, User's Reference Manual, Washington, D.C., 1977.

11. Nielsen, Viggo Dam and Shahal, Haim, Application of Life Support Cost, Provisioning, and Repair/Discard Models to Weapon System Procurement Decisions by Small Countries, Master's Thesis, Naval Postgraduate School, Monterey, California, 1981.

12. Naval Air Systems Command, Avionic Equipment Default Data Guide for Level of Repair MOD III, Washington, D.C., 1982.

13. Neches, Thomas M., A Critical Review of Level of Repair Models, The Assessment Group, Santa Monica, California, 1983.

14. Naval Supply Systems Command, Standard Data Element Dictionary, NAVSUP PUB 508, Washington, D.C., 1974.

15. CACI, Inc., ACIM: An Availability Centered Inventory Model, Handbook Release 2.0, Arlington, Virginia, 1982.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Professor M.B. Kline, Code 54Kx Naval Postgraduate School Monterey, California 93943	10
4.	Professor A. McMasters, Code 54Mg Naval Postgraduate School Monterey, California 93943	1
5.	Dr. L. Crow U.S. Army Material Systems Analysis Activity Aberdeen Proving Ground, Maryland 21005	1
6.	Mr. R.R. Shorey Director, Weapon Support Office of the Secretary of Defense Assistant Secretary (MRA&L) Washington, D.C. 20301	1
7.	Mr. M. McGrath Office of the Secretary of Defense Assistant Secretary (MRA&L) Washington, D.C. 20301	1
8.	Ron Golembiowski, AIR-41111B7 Naval Air Systems Command Headquarters Washington, D.C. 20361	1
9.	CACI, Inc. Federal Operations and Management Analysis Department 2361 Jefferson Davis Highway ML101 Arlington, Virginia 22202	1
10.	Lt. Henry J. Watras, USN Air Department USS J.F. Kennedy, CV-67 FPO New York, New York 09501	2

END

FILMED

3-84

DTIC